INSTRUCTION MANUAL

Type 874-LBB SLOTTED LINE

GENERAL RADIO COMPANY

INSTRUCTION MANUAL

Type 874-LBB | SLOTTED LINE

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Form 0874-0205-A August, 1966

GENERAL RADIO COMPANY
WEST CONCORD, MASSACHUSETTS 01781

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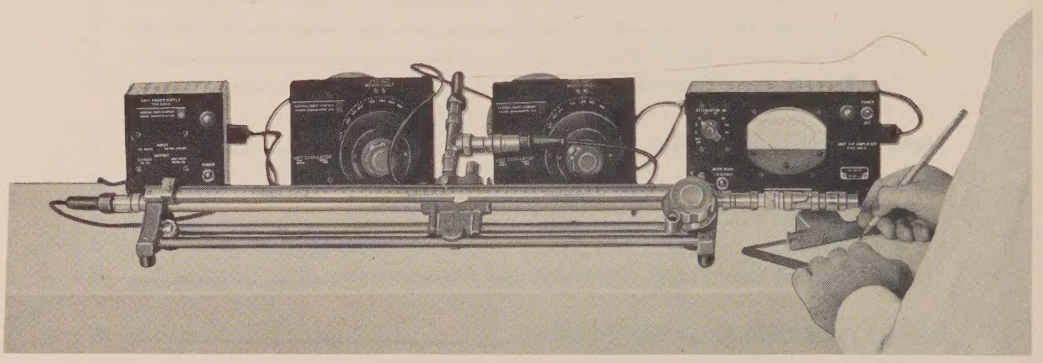
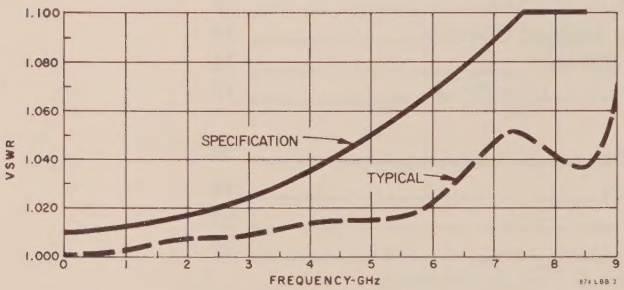
The Type 874-LBB Slotted Line and the Type 874-W50, 50-ohm Termination Unit are shown connected for the measurement of the VSWR of Type 874-QN Adaptors. These adaptors are used to connect components fitted with type N Connectors to devices fitted with Type 874 Connectors.



SPECIFICATIONS

Characteristic Impedance: 50 ohms, ± 0.5%.
Residual VSWR:
Less than 1.01. + 0.0016 f_{GHz}^2 up to 7.5 GHz
Less than 1.10 from 7.5 to 8.5 GHz.



Type 874-LBB residual VSWR.

NOTE
Type 874-BBL locking connectors are used in establishing the residual VSWR specifications.

Scale Accuracy: ±(0.1 mm + 0.05%).
Frequency Range: 300 MHz to 8.5 GHz. At 300 MHz the slotted line covers one half wavelength. Operation below 300 MHz and to 9 GHz is possible.
Probe Travel: 50 cm. Scale calibrated in cm; each division is 1 mm.
Constancy of Probe Penetration: ±1.25%.
Accessories Supplied: Rf probe (with Type 874-BL connector); 1N21C and 1N23B detector diodes; storage case; sample Smith Charts.
Accessories Required: Adjustable stub (Type 874-D20L or 900-DP) for tuning the diode rectifier when audio frequency detector or microammeter is used, suitable detector and generator, Type 874-R22LA Cords for generator and detector connections.
Accessories Available: Type 874-LV Micrometer Vernier carriage drive, Type 900-DP Probe Tuner; a vast array of connectors and adaptors (see list of GR874 components at the rear of the manual).
Dimensions: 26 by 4½ by 3½ inches (660 by 115 by 90 mm), over-all.
Net Weight: 8½ pounds (3.9 kg).

Several copies of Smith Charts are supplied with the Slotted Line. Additional copies can be obtained from General Radio at the following prices:

Catalog Number	*Description*	
5301-7568	**Type Y Smith Chart**	(20-mmho admittance coordinates)
5301-7569	**Type Z Smith Chart**	(50-ohm impedance coordinates)
5301-7560	**Type N Smith Chart**	(normalized coordinates)
5301-7561	**Type NE Smith Chart**	(normalized expanded coordinates)
5301-7562	**Type HE Smith Chart**	(normalized highly expanded coordinates)

Price per unit of 50 (minimum quantity sold)

No. of units	1	2–3	4–9	10–19	20 and over
Price	**$2.00**	**$1.90**	**$1.75**	**$1.40**	**$1.25**

SECTION 1 INTRODUCTION

1.1 PURPOSE

The Type 874-LBB Slotted Line is a coaxial instrument basic to the measurement of the impedance, voltage standing wave ratio (VSWR), and reflection coefficient of distributed and lumped elements from 300 MHz to 8.5 GHz,

The Slotted Line is fitted with Type 874-BBL Connectors. It is extremely versatile for it can be used, through adaptors, with most other standard coaxial line elements, including the very precise GR900 line.

1.2 DESCRIPTION

The Type 874-LBB Slotted Line is designed to measure accurately the voltage standing-wave pattern produced by any load connected to it. Its characteristic impedance is 50 ohms. The outer conductor is slotted for a length of approximately 50 centimeters, and a small shielded probe extends into the region between the two conductors. The probe is mounted on a carriage, which slides along the outside of the outer conductor. The penetration of the probe into the line and, hence, the capacitive coupling between the probe and the line, can be adjusted over a wide range by means of a screw adjustment.

Since the probe is capacitively coupled to the line, the voltage induced in the probe circuit is proportional to the voltage existing between the inner and outer conductors of the line at the probe position.

The carriage is driven by means of a nylon cord which passes around a drum mounted on the casting at one end of the line and around an idler pulley which is mounted on the casting at the other end of the line. The driving knob is attached to the same shaft as the drum. The drive depends upon friction. This drive method facilitates recorder-driving of the slotted-line.

1.3 ACCESSORIES SUPPLIED

With the Type 874-LBB Slotted Line are supplied two detector diodes, an rf probe (with Type 874-BL Connector), a storage case, and a few Smith charts.

1.4 ACCESSORIES REQUIRED

Required to operate the Type 874-LBB Slotted Line are a suitable generator and detector (refer to Section 2), and an adjustable probe (Type 874-D20L), or a Type 900-DP Probe Tuner, for tuning the diode rectifier when the audio frequency detector or the microammeter is used. The Type 900-DP Probe Tuner is recommended for the greatest convenience and accuracy.

SECTION 2 INSTALLATION

2.1 GENERAL

The Type 874-LBB requires a laboratory quality rf signal source, a standing-wave meter and means of tuning the detector (adjustable stub or probe tuner) to be ready for operation.

The line is compatible with all commercial instruments available as rf source and indicator. Table 2-1 lists the recommended General Radio generators; suggested hookups are shown in Figures 2-1, 2-2, and 2-3.

Table 2-2 lists some of the adaptors available and Figures 2-7 a, b, and c show the residual VSWR performances of the line and adaptors.

2.2 GENERATOR

The generator requirements are dependent on the type of detector used and on the standing-wave ratio of the load to be measured. Table 2-1 is a chart showing several possible generators with their respective frequency ranges. The Type 1264 Modulating Power Supply is an ideal source of 1-kHz square-wave modulation as well as a regulated power supply, for the unit oscillators in slotted-line uses.

TABLE 2-1 GENERATORS

Type	*Name*	*Frequency Range*
1215	Unit Oscillator	50- 250 MHz
1209-C	Unit Oscillator	250- 960 MHz
1209-CL	Unit Oscillator	180- 600 MHz
1208	Unit Oscillator	65- 500 MHz
1361	UHF Oscillator	500-1000 MHz
1218	Unit Oscillator	900-2000 MHz
1360	Microwave Oscillator	1.7- 4.0 GHz

2.3 DETECTOR

2.3.1 GENERAL

Either the built-in diode detector (using one of the two diodes supplied), or an external receiver can be used as a detector.

The choice of microwave diode depends upon operating frequency, since such diodes have a self-resonant frequency which may reduce sensitivity slightly and broaden the tuning-stub resonance. Two diodes (types 1N21C and 1N23B) with different resonant frequencies are supplied. If the above condition is encountered, it can be eliminated by interchange of diodes. Note that a diode is used only with a modulated signal source.

CAUTION

The diode should be removed before unscrewing the RF Probe or the Probe Tuner.

If desired, Type 610-A Bolometer elements, manufactured by Polytechnic Research and Development Company or similar bolometers can be inserted in place of the diode. With bolometers, less attention is required relative to operation in the square-law region.

2.3.2 DIODE RECTIFIER AND STANDING WAVE METER

The most commonly used and the most generally satisfactory detector is the built-in diode rectifier, with one of the several commercially available VSWR meters (Figure 2-1). The oscillator driving the line should be modulated, preferably square wave.

At very low levels, the diode operates in the "square-law" portion of its characteristic curve, that is, the rectified output is proportional to the square of the rf input. At high levels, the diode approaches a linear characteristic. For reference: for a rectified output of up to 2 mV, the supplied diodes operate in their square-law region. This will be the case for most measurements.

The diode rectifier is tuned by means of the adjustable stub (Type 874-D20L) or the Type 900-DP Probe Tuner. (Refer to paragraph 3.4.)

2.3.3 HETERODYNE DETECTOR

The Type DNT Detector (Figure 2-2) is also a satisfactory detector for the slotted line, particularly for the measurement of high VSWR's, because of its good sensitivity and harmonic rejection. It is recommended when the minimum position must be determined accurately, such as in the measurement of electrical length. It is also preferable when measuring by the width-of-minimum method.

The shielding of this detector is excellent, a property which is useful in the measurement of radiating systems. Harmonics of the local oscillator frequency can be used to beat with the signal from the

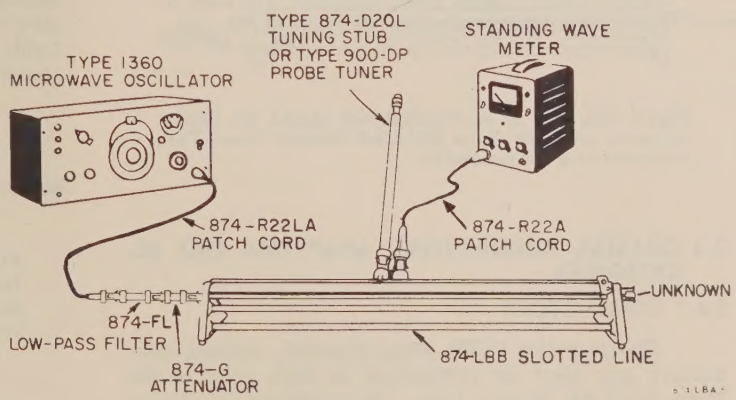


Figure 2-1. Use of a modulated source for measurements with the Type 874-LBB Slotted Line. The built-in diode detector and a standing-wave meter are used to detect the voltage induced in the probe. The probe is tuned by means of the adjustable stub shown, or a Type 900-DP Probe Tuner.

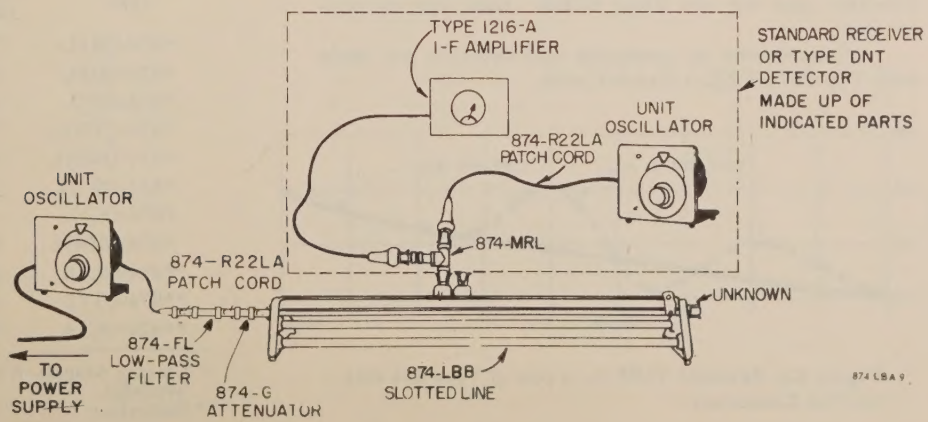


Figure 2-2. Use of an unmodulated source and a superheterodyne detector or receiver for measurements with the Type 874-LBB Slotted Line.

slotted line. Hence, the upper frequency limit may be several times the upper frequency limit of the oscillator.

NOTE

The diode must be removed from the carriage mount in this application.

2.3.4 DIODE RECTIFIER AND MICROAMMETER

A simple detector system consists of the built-in diode rectifier used with an external microammeter, as shown in Figure 2-3. In this case, the rectified dc output of the diode is measured on a sensitive microammeter connected between the inner and outer terminals of the right-hand connector on the probe carriage. In most cases, the rectified dc output is closely proportional to the square of the rf input at currents up to roughly 50 microamperes.

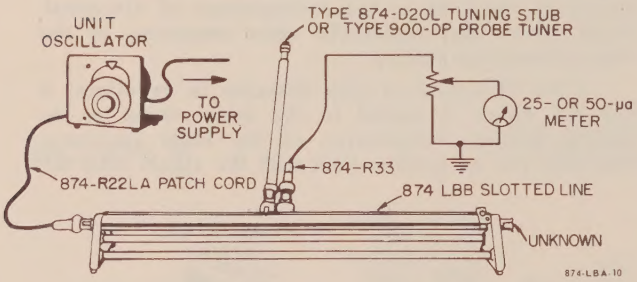


Figure 2-3. Use of an unmodulated source for measurements with the Type 874-LBB Slotted Line. The indicator is a microammeter.

2.4 COAXIAL CONNECTORS, ADAPTORS AND ACCESSORIES

2.4.1 CONNECTORS

The new low VSWR Type 874-BBL locking connectors are used for connection at both ends of the Type 874-LBB Slotted Line. The improvement due to the Type 874-BBL is evident in the graph of Figure 2-4 which shows the residual VSWR of both the Type 874-BBL and the old Type 874-B (one pair of connectors).

Connections to generator and detector are made with Type 874-R22LA Patch Cords.

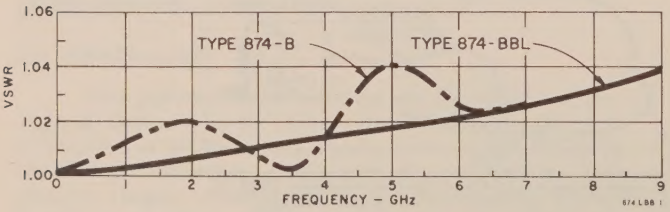


Figure 2-4. Residual VSWR for a pair of Type 874-BBL Locking Connectors.

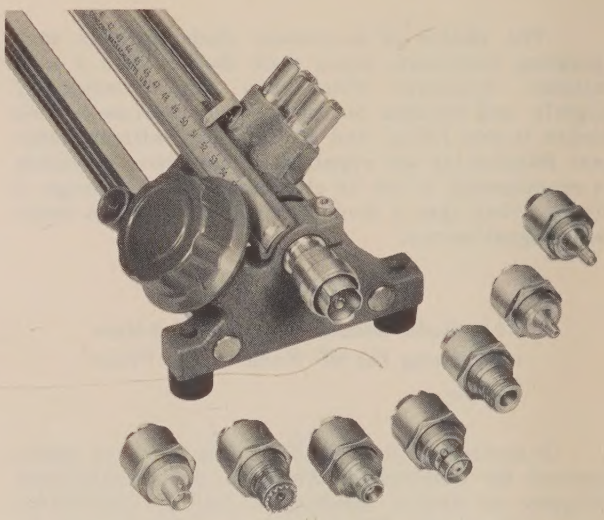


Figure 2-5. The Type 874-LBB and some of the GR adaptors.

2.4.2 ADAPTORS

If the unknown, the generator or the detector, is fitted with connectors other than the Type 874, adaptors can be used to make the necessary transition to the Type 874 connectors. The conversion to all the other leading coaxial connectors series is fast and inexpensive. The performance is excellent in those line sizes. Table 2-2 lists some of the GR adaptors; Figure 2-5 shows them with the slotted line.

Connection to the more precise GR900 line is also offered, through the Type 900-Q874 (Figure 2-6).

Figure 2-6. The Type 900-Q874 converts the GR874 line to the GR900 line.

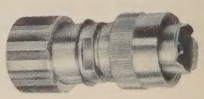
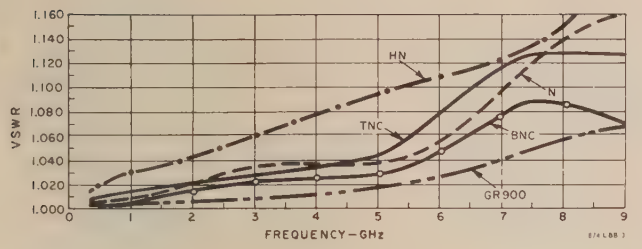


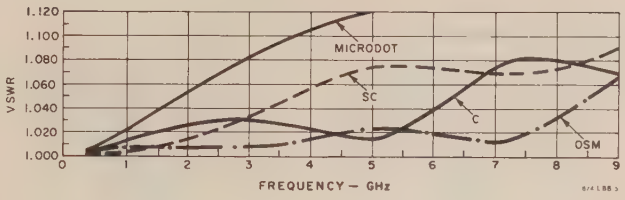
TABLE 2-2 GR874 ADAPTORS

Type	*Contains GR874 and . . .*	*Connects GR874 and . . .*
*874-QBJL	BNC jack	BNC plug
*874-QHJL	HN jack	HN plug
*874-QNJL	N jack	N plug
*874-QTNJL	TNC jack	TNC plug
*874-QMDJL	Microdot jack	Microdot plug
*874-QSCJL	SC jack	SC plug
*874-QCJL	C jack	C plug
*874-QMMJL	OSM jack	OSM plug
**874-QLJA	LC jack	LC plug
**874-QJTJ	LT jack	LT plug
**874-QU1A	7/8 rigid line	7/8 rigid line

* Locking Adaptor. A nonlocking version of jack and plug is available.
** Nonlocking



(a)



(b)

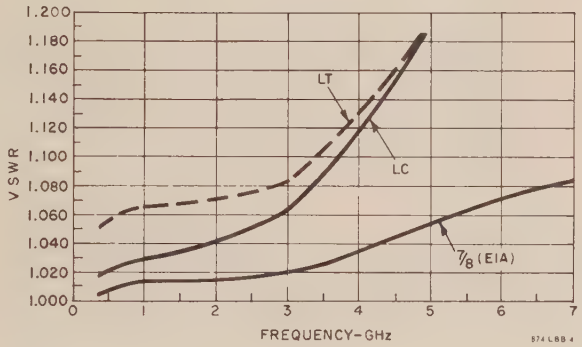
2.4.3 RESIDUAL VSWR OF THE TYPE 874-LBB LINE WITH DIFFERENT ADAPTORS

Quite naturally, the Type 874-LBB Slotted Line will have a different residual VSWR performance when terminated in an adaptor.

The graphs in Figures 2-7 a, b and c show residual VSWR for the Type 874-LBB when fitted with different adaptors (locking connectors). These curves are not to be taken as specifications but rather as typical.

2.4.4 COAXIAL ACCESSORIES

In addition to the adaptors, there are available Type 874 tees, ells, air lines, rotary joints, and other accessories for convenience of connection. Refer to the list at the rear of this manual or, for full description, to the latest General Radio Catalog.



(c)

Figure 2-7. Residual VSWR on the Type 874-LBB line fitted with the different adaptors indicated on the graphs.

SECTION 3 OPERATING PROCEDURE

3.1 GENERAL

Once the rf generator, the detecting system and the different accessories have been chosen (Section 2) the probe penetration has to be adjusted (paragraph 3.3) and the detector has to be tuned (paragraph 3.4) then the slotted line is ready to operate (paragraph 3.5 and subsequent paragraphs).

Often the line will have to be short- or open-circuited and these operations are discussed first (refer to paragraph 3.2).

3.2 METHODS OF SHORT- AND OPEN-CIRCUITING A LINE.

The method of producing a short-circuit for line-length measurement or adjustment is important. When an antenna or other element terminating a line is measured, the short circuit can be made, as shown in Figure 3-1.

An accurately positioned open-circuit is more difficult to obtain than an accurately positioned short-circuit because of fringing capacitance. Compensation for this effect is provided in the open-circuit termination described below.

The recommended method of producing a short- or open-circuit is to use a Type 874-WN, -WNL or -WN3 Short-Circuit Termination or Type 874-WO, -WOL or -WO3 Open-Circuit Termination Unit. The -WN3 and -WO3 Units produce a short- or open-circuit at a physical distance of 3 cm (3.2 cm electrical distance) from the front face, on the measuring instrument side of the insulating bead, as shown in Figure 3-1 a. The front face of the bead is located at the bottom of the slots between the contacts on the outer conductor.

The Types 874-WN, -WNL or -WO, -WOL Termination Unit produce a short or open circuit directly at the front face of the insulating bead (Figure 3-1 b and 3-1 c). In the case of the locking terminations the reference plane set up by these locking terminations on the slotted-line is nominally 0.025-inch, toward the load because of the inherent disengagement of the locking connectors. These units can be used even if the impedance is desired at a point on the line other than at the face of the bead, if the electrical distance between the two points is added to or subtracted from the line length measured with the short- or open-circuit termination unit connected. The electrical line length for air dielectric line is equal to the physical length. Each bead in the Type 874 connector has an electrical length of 0.55 cm.

To determine the impedance at the input to a coaxial circuit connected to the slotted line, a Type 874-WN or -WNL Short-Circuit can be used to produce a short circuit directly at the front face of the insulating bead in the Type 874 Connector on the circuit under test. (The front face of the bead is located at the bottom of the slots in the outer conductor.)

3.3 PROBE PENETRATION ADJUSTMENT

3.3.1 GENERAL

The probe penetration should be adjusted for adequate sensitivity as well as insignificant effect on the measured VSWR. The presence of the probe affects the VSWR because it is a small admittance in shunt with the line. It has the greatest effect at a voltage maximum, where the line impedance is high.

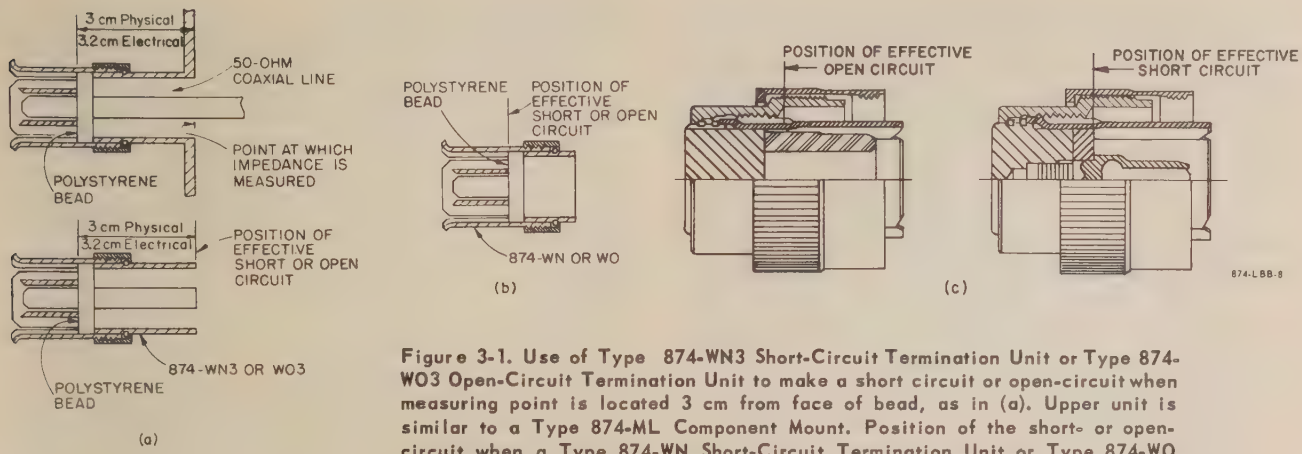


Figure 3-1. Use of Type 874-WN3 Short-Circuit Termination Unit or Type 874-WO3 Open-Circuit Termination Unit to make a short circuit or open-circuit when measuring point is located 3 cm from face of bead, as in (a). Upper unit is similar to a Type 874-ML Component Mount. Position of the short- or open-circuit when a Type 874-WN Short-Circuit Termination Unit or Type 874-WO Open-Circuit Termination Unit is used (b). Locking-type terminations used in (c).

3.3.2 TYPE 900-DP PROBE TUNER

Adjust probe penetration by means of the small control knob at the top of the tuning stub, as shown in Figure 3-2. Set it at 0.100 for routine measurements. The adjustment scale is calibrated in thousandths of an inch and reads the distance between the tip of the probe and the center conductor of the slotted line. A stop, which prevents the probe from touching the center conductor, holds the minimum distance to about 0.010 inch; maximum is about 0.150 inch after initial adjustment.

The effect of the probe coupling on the residual reflection coefficient of the slotted line is shown in Figure 3-3, or it can be determined by measurement of the VSWR at two different degrees of coupling. If the measured VSWR is the same in both, the probe coupling used has no significant effect on the measurement. If the measured VSWR's are different, additional measurements should be made, with decreasing amounts of probe penetration, until no difference occurs.

CAUTION

Always remove the diode prior to installation or removal of tuner.

Figure 3-2. Probe depth control.

3.3.3 RF PROBE

If connected, remove the tuning stub from the left hand connector in order to change the penetration and turn the small screw found inside the inner connector. Clockwise rotation increases penetration.

CAUTION

Do not screw this probe down tight against the center conductor of the slotted line, as it will damage the probe or the center conductor. Always remove the diode prior to installation or removal or probe.

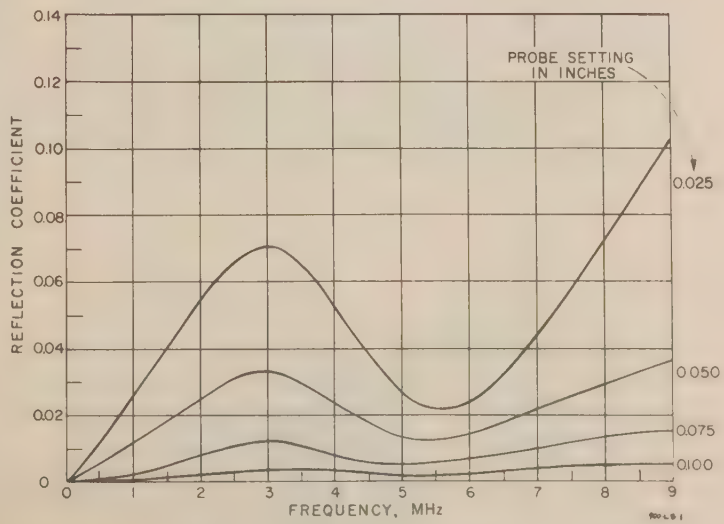


Figure 3-3. Typical probe reflections at four penetrations.

In most cases in which moderate VSWR's are measured, a distance of 0.1-inch from the inner conductor to the probe (Figure 3-4 a) will give the best results. This is achieved by backing off 5.5 turns of the screw after contact between probe and inner conductor has been made. Contact has to be very carefully approached and the following method is to be used:

Short the end of the line and connect an ohmmeter as shown in Figure 3-4 b. Contact is made when the ohmmeter shows conductivity (ohmmeter on R x 100 or x 1000).

NOTE

The diode has to be present in this procedure but the polarity of the ohmmeter has to be such that the forward resistance (low) of the diode is measured. The backward resistance is so high that it would make a reading of conductivity very difficult.

The amount of probe penetration can be visually checked by looking at the probe through the slot from one end of the line.

3.3.4 VARIATION IN PROBE COUPLING

The variation in probe coupling along the line is affected by the depth of penetration. At large penetration the variation tends to increase. The specified 1.25% holds for a penetration of 0.1-inch out (Figure 3-4 a).

When performing electrical length measurements (high VSWR), greater penetration may be employed. The probe is at a voltage minimum and therefore has a minimal effect on the position of the standing wave minimum.

3.4 DETECTOR TUNING

3.4.1 DIODE RECTIFIER TUNING

The diode rectifier built into the carriage is tuned either by means of the Type 900-DP Probe Tuner for highly sensitive tuning or by the adjustable stub (Type 874-D20L). These are effectively connected in parallel with the rectifier in order to increase the sensitivity and to provide selectivity. The probe tuner or the stub is adjusted until maximum output is indicated by the detector. Readjust the signal level as necessary to keep the audio output of the diode below 2 mV, which ensures operation in its square-law region.

Be sure the stub (or the probe tuner) is not tuned to a harmonic of the desired signal rather than to the fundamental. Confusion may result in some cases if the tuning is done with a high VSWR on the line, as the minima of the harmonics may not be coincident with the minima of the fundamental. To minimize the possibility of mistuning, the probe should be tuned with a low VSWR on the line, for instance, with the line terminated in a Type 874-W50B, -W50BL Termination Unit. As a check, the distance between two adjacent voltage minima on the line can be measured. If the stub (or the probe tuner) is tuned correctly, the spacing should be half a wavelength.

The diode can be tuned to frequencies from about 275 MHz to 8.5 GHz with the Type 874-D20L Adjustable Stub, from 300 MHz to 8.5 GHz with the Type 900-DP Probe Tuner.

For operation at frequencies below 275 MHz a Type 874-D50L Adjustable Stub can be used down to 150 MHz or various lengths of Type 874-L Air Line can be inserted in series with the adjustable stub.

3.4.2 HETERODYNE DETECTOR

When the DNT Detector is used, care must be taken to tune the local oscillator to beat with the desired signal and not with one of its harmonics. Harmonics of the oscillator signal can beat with harmonics of the signal picked up from the slotted line and produce an output at the intermediate frequency, if the local oscillator is tuned to a wrong frequency. Proper settings of the local oscillator are given by the following expression, assuming that the intermediate frequency is 30 MHz:

$$f_{LO} = \frac{f_S \pm 30}{n}$$

where f_{LO} is the frequency of the local oscillator, f_S is the signal frequency, and n is an integer, corresponding to the harmonic of the local-oscillator signal used. Always use the lowest possible harmonic.

If n = 1, there are two possible settings of the local oscillator, separated by 60 MHz and centered about the signal frequency. If n = 2, the two possible settings are separated by 30 MHz and are centered about f_S/n.

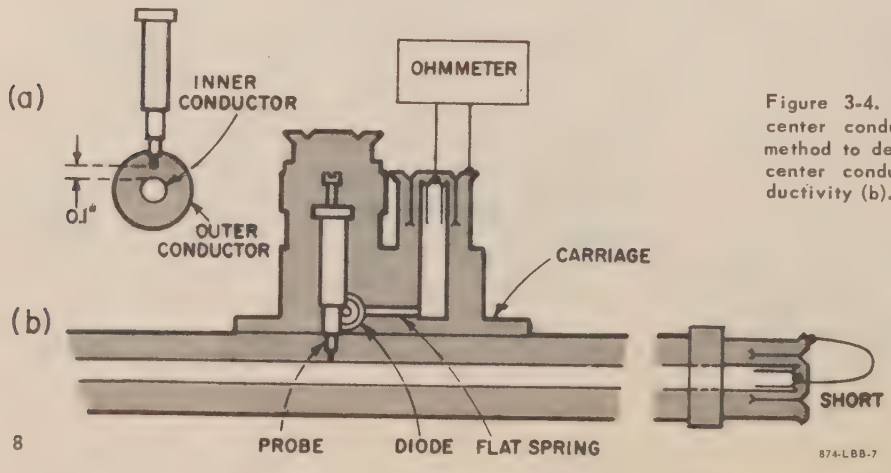


Figure 3-4. The distance between probe and center conductor for best results (a). Best method to determine that the probe touches the center conductor; the ohmmeter shows conductivity (b).

In the general case, the two possible settings are separated by 60/n and are centered about the frequency f_S/n.

The second harmonic of the desired signal frequency will produce a beat frequency of 30 MHz when the local-oscillator frequency is

$$f_{LO} = \frac{2f_S \pm 30}{n} = \frac{f_S \pm 15}{\frac{n}{2}}$$

or, in general,

$$f_{LO} = \frac{f_S \pm \frac{30}{h}}{\frac{n}{h}}$$

where h is the harmonic of the signal frequency. It can be seen from the above equation that some of the harmonic responses may be located reasonably close to the frequency at which the fundamental is detected. The higher the harmonic of the local oscillator, the closer will be the spurious responses.

In general, spurious responses do not cause much difficulty, as the frequency to which the detector is tuned can be easily checked by measuring the distance between two voltage minima on the line, which should be half a wavelength at the operating frequency. The use of an appropriate Type 874-F Low-Pass Filter is often convenient in these cases.

At some frequencies it is necessary to insert a Type 874-L10L, 10-cm Air Line, between the connector on the carriage and the mixer rectifier, in order to develop sufficient local-oscillator voltage across the diode.

3.5 MEASUREMENT OF WAVELENGTH

The free-space wavelength of the exciting wave can be measured using the slotted line by observing the separation between adjacent voltage minima when the line is short- or open-circuited. The spacing between adjacent minima, d is one-half wavelength or

$$\lambda = 2d$$

For greater accuracy at the higher frequencies, the distance over a span of several minima can be measured. If the number of minima spanned, not counting the starting point, is n, then

$$\lambda = \frac{2d}{n}$$

3.6 MEASUREMENT OF LOW VSWR (BELOW 10:1)

3.6.1 TWO METHODS

When the standing-wave ratio to be measured is less than about 10:1, the VSWR can be read directly on the scale of a standing-wave indicator (follow the manufacturer's instructions); or, with the Type 1232 Tuned Amplifier and Null Detector or the Type DNT Detector, it can be determined from the difference between the two decibel-scale readings corresponding to the voltage maximum and voltage minimum on the slotted line.

The dB difference can be converted to VSWR on the auxiliary scales at the bottom of the Smith Chart or can be computed from the expression

$$VSWR = \log^{-1} \frac{dB}{20}$$

When using the Type 1232 Amplifier with a square-law detector, the difference in dB must be divided by two to obtain the value to use in the above formula.

The probe coupling can vary a maximum of 1.25% along the line, and the VSWR measured is in error by the difference in coupling coefficients at the maximum and minimum voltage points. This error can be avoided by calibration of the variation of coupling with probe position, as outlined in paragraph 5.5, or it can be reduced greatly by measuring several minima and several maxima, then averaging the results.

3.6.2 DETERMINATION OF IMPEDANCE FROM VSWR

To determine the impedance of the unknown, the VSWR and the electrical distance between a voltage minimum on the line and the unknown must be determined. The unknown impedance is calculated as outlined in paragraphs 4.3 and 4.4.

To find the effective distance to the unknown, short-circuit the line with a very-low-inductance short at the position of the unknown (refer to paragraph 3.2) and measure the position of a voltage minimum on the line. This minimum is an integral number of half-wavelengths from the unknown. Since the impedance along a lossless line is the same every half-wavelength, the position of the voltage minimum found with the line short-circuited is the effective position of the unknown.

3.6.3 BROAD MINIMUM

When the VSWR is very low, the minima will be very broad, and it may be difficult to locate the minimum positions accurately. In this case, better results usually can be obtained by measuring the positions of points on either side of a voltage minimum at which the voltage is roughly the mean of the minimum and maximum voltages, as shown in Figure 3-5. The minimum is located midway between these two points.

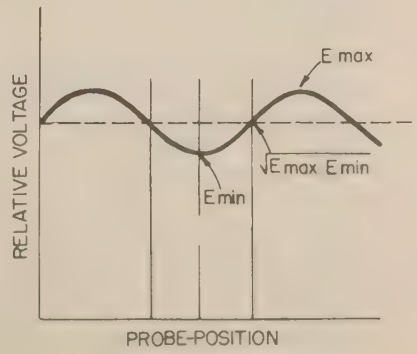


Figure 3-5. Method of improving the accuracy of the determination of the position of a voltage minimum on the line when the VSWR is low.

(Either the geometric or the arithmetical mean can be used. It is necessary only to have an identifiable value.)

3.6.4 ADDITIONAL PRECAUTIONS

If the line connecting the unknown to the slotted line has a significant amount of loss, a correction can be made for the effect of the loss on the unknown impedance, as outlined in paragraph 3.7.2.

Harmonics of the oscillator frequency may also cause an error in VSWR measurement, as discussed in paragraph 3.7.6. The effect will tend to be most serious when the VSWR at the harmonic frequencies is high. A low-pass filter installed at the input is recommended to reduce this error.

3.7 MEASUREMENT OF HIGH VSWR

3.7.1 LIMITATIONS

When the VSWR on the line is 10 to 1 or more, direct accurate measurements of a voltage maximum and a voltage minimum are difficult because:

1. The effect of a fixed probe-coupling coefficient on the measurement increases as the VSWR increases, because the line impedance at the voltage maximum increases and the shunt impedance produced by the probe has greater effect.
2. As the VSWR increases, the voltage at the voltage minimum usually decreases and, hence, a greater probe-coupling coefficient is required to obtain adequate sensitivity. The increased probe coupling may cause errors as outlined in 1 above.
3. The accuracy of the measurement of the relative voltage decreases as the VSWR increases. The voltage range becomes too great to permit operation entirely in the square-law region. (Not applicable when heterodyne detector is employed.)

3.7.2 USE OF A HETERODYNE DETECTOR

All three of the above restrictions can be reduced in effect, or eliminated, by employing a heterodyne detector such as the DNT systems.

1. The probe may be retracted because of the greater sensitivity of the DNT detectors. (Approximately 30 dB more sensitive than the square-law, video, detector .) Greatest sensitivity can be achieved by teeing in an adjustable stub (Type 874-D20L) at the mixer input. Retraction of the probe reduces the shunting effect.
2. The heterodyne detector has considerably greater sensitivity than the video detector; (a video detector is defined as a diode detector plus a 1 KHz amplifier, employed with a modulated source).
3. The heterodyne detector has a large dynamic range; it is accurately used over about an 80-dB range.
4. The source need not be modulated. This improves accuracy because incidental FM produced by modulation is reduced, and the possibility of klystron source moding is eliminated.

3.7.3 WIDTH OF MINIMUM METHOD

Accurate measurements of VSWR's greater than 10 can be made using the width-of-minimum method. This is analogous to the determination of circuit Q by measurement of the frequency increment between the two half-power points. In the slotted-line case, the spacing, Δ, between points on the line at which the rf voltage is $\sqrt{2}$ times the voltage at the minimum, is measured, as shown in Figure 3-6. The VSWR is related to the spacing, Δ, and the wavelength, λ, by the expression

$$\text{VSWR} \cong \frac{\lambda}{\pi \Delta}$$

If the detector is operating in the square-law region, $\sqrt{2}$ times the rf voltage corresponds to twice the minimum rectified output, or a 6-dB change in output.

All standing wave meters are calibrated to take the square-law operation into account, therefore, a 3-dB change will be indicated.

For very sharp minima, the width of the minimum can be measured to a much greater accuracy by use of the Type 874-LV Micrometer Vernier than by means of the centimeter scale on the slotted line. The vernier can be read to ±0.002 cm. When the vernier is used, the probe is moved slightly to the right of the minimum and the vernier is adjusted to have its plunger strike the carriage on the unpainted surface below the output connector. To adjust the position of the vernier, loosen the thumbscrew which clamps the vernier to the reinforcing rod, slide it along to the proper position, and relock it.

Then, drive the probe through the minimum and the twice-power points by turning the micrometer screw. Determine the output-meter reading corresponding to the minimum; set the standing-wave indicator for 6 dB more attenuation.

Back off the micrometer and return the probe to the right side of the minimum. Then, again drive the probe through the minimum and twice-power points and note the two micrometer readings corresponding to the original output meter reading. The difference between these readings is equal to Δ.

If the minimum is too close to the right-hand end of the line to permit the use of the vernier in the usual manner, the vernier can be moved to the left-hand side of the carriage and the other end of the plunger can be used to drive the carriage.

The electrical distance between the unknown and the minimum found on the line can be determined as outlined in paragraph 3.6.2.

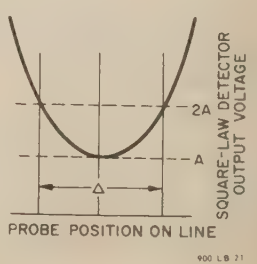


Figure 3-6.
Method of measuring the width of the voltage minimum for VSWR determinations when the VSWR is high.

At very high standing-wave ratios, the losses in the slotted line and in any connecting line or cable used can have an appreciable effect on the measurements. To keep this error as low as possible, the voltage minimum nearest the load should be measured. A correction for the loss in the line can be made as outlined in paragraph 3.7.4.

3.7.4 CORRECTION FOR LOSS IN LINE BETWEEN MEASURING POINT AND UNKNOWN

When a load is connected to the slotted line through a length of air line or cable, the loss in the air line or cable may appreciably affect the measurements. Loss in the cable tends to make the measured VSWR less than the true VSWR produced by the load. For extremes of VSWR or impedance even the slotted-line loss can affect the measurements.

The amount of loss in a length of cable can be estimated from the published cable data or can be measured. The slotted-line loss should be measured for greatest accuracy. The loss and the loss correction for VSWR can be determined by first short-circuiting then open-circuiting the cable or slotted-line. The Type 874-WN or -WNL, and the Type 874-WO or -WOL are recommended for this purpose. If the line is perfectly uniform, then only a short-circuit or only an open-circuit measurement is required, as is also the case when the highest accuracy is not required. The relation between the attenuation, $A = \alpha l$, and the measured reflection coefficients, Γ_M, is,

$$A = 10 \log_{10} \left|\Gamma_M\right| \quad \text{dB}$$

$$\text{where } \left|\Gamma_M\right| = \sqrt{\left|\Gamma_{SC}\right| \times \left|\Gamma_{OC}\right|}$$

Γ_{SC} = reflection coefficient with short-circuit connected

Γ_{OC} = reflection coefficient with open-circuit connected

Note that $\left|\Gamma\right| = \dfrac{\text{VSWR} - 1}{\text{VSWR} + 1}$

A quantity employed below, for loss correction derived from Γ_M, is

$$\frac{1}{(\text{VSWR})_L} = \frac{\left|\Gamma_M\right| - 1}{\left|\Gamma_M\right| + 1}$$

The attenuation can also be determined from the short-circuit and open-circuited VSWR by use of the TRANSMISSION LOSS and STANDING WAVE RATIO scales located below the Smith Chart, shown in Figure 3-8. The point corresponding to this VSWR is located on the $\dfrac{E_{MAX}}{E_{MIN}}$ or DB scales under STANDING WAVE RATIO. At the same distance from the center, find a corresponding point on the TRANSMISSION LOSS scale. Attenuation of the line is equal to the number of decibels between the left-hand end of the scale labeled 1 DB STEPS and this latter point.

In most cases the loss in the slotted line itself can be neglected, but the loss in the line or cable used to connect the slotted line and the load is usually of importance. The unknown impedance can then be calculated in the same manner as for the lossless case, if the measured voltage standing-wave ratio, $(\text{VSWR})_M$, is first corrected for the effect of the loss in the line. The actual or true voltage standing-wave ratio, (VSWR), is then exactly

$$(\text{VSWR}) = \frac{(\text{VSWR})_M - \dfrac{1}{(\text{VSWR})_L}}{1 - \dfrac{(\text{VSWR})_M}{(\text{VSWR})_L}}$$

3.7.5 CORRECTION FOR LOSS IN THE CONNECTOR

In the measurement of a very high VSWR, the loss at the Type 874 Connector on the slotted line can have an important effect. The magnitude of this loss for a typical line is plotted in Figure 3-7. The loss can be considered as being caused by a lumped series resistance at the lower frequencies shown.

Correction for loss as described in paragraph 3.7.4 assumes loss uniformity on the transmission line and slotted-line. As indicated here, lumped losses, occur for example in the connector, and this loss can produce an error in loss-correction. This error can be eliminated essentially by employing a substitution method. A short-circuit or open-circuit is constructed, employing a low-loss section of line, to produce a

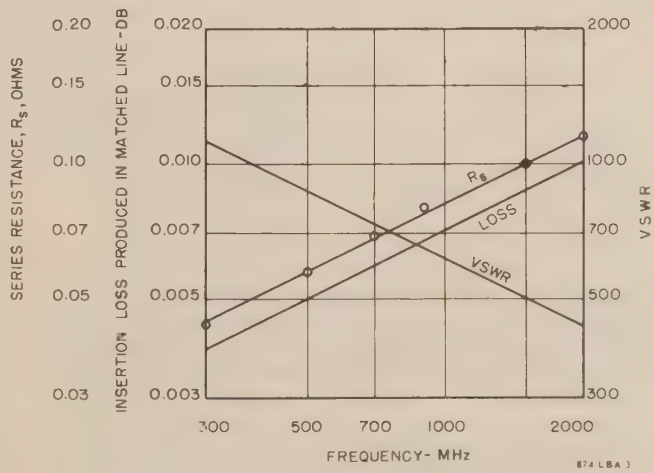


Figure 3-7. Plot of the effect of loss in the connector, measured on a typical Type 874-LBB Slotted Line. The insertion-loss produced in a matched line and the corresponding value of series resistance is also indicated, as well as the VSWR which would be produced by the connector in an open- or short-circuited 50-ohm line that has no other losses.

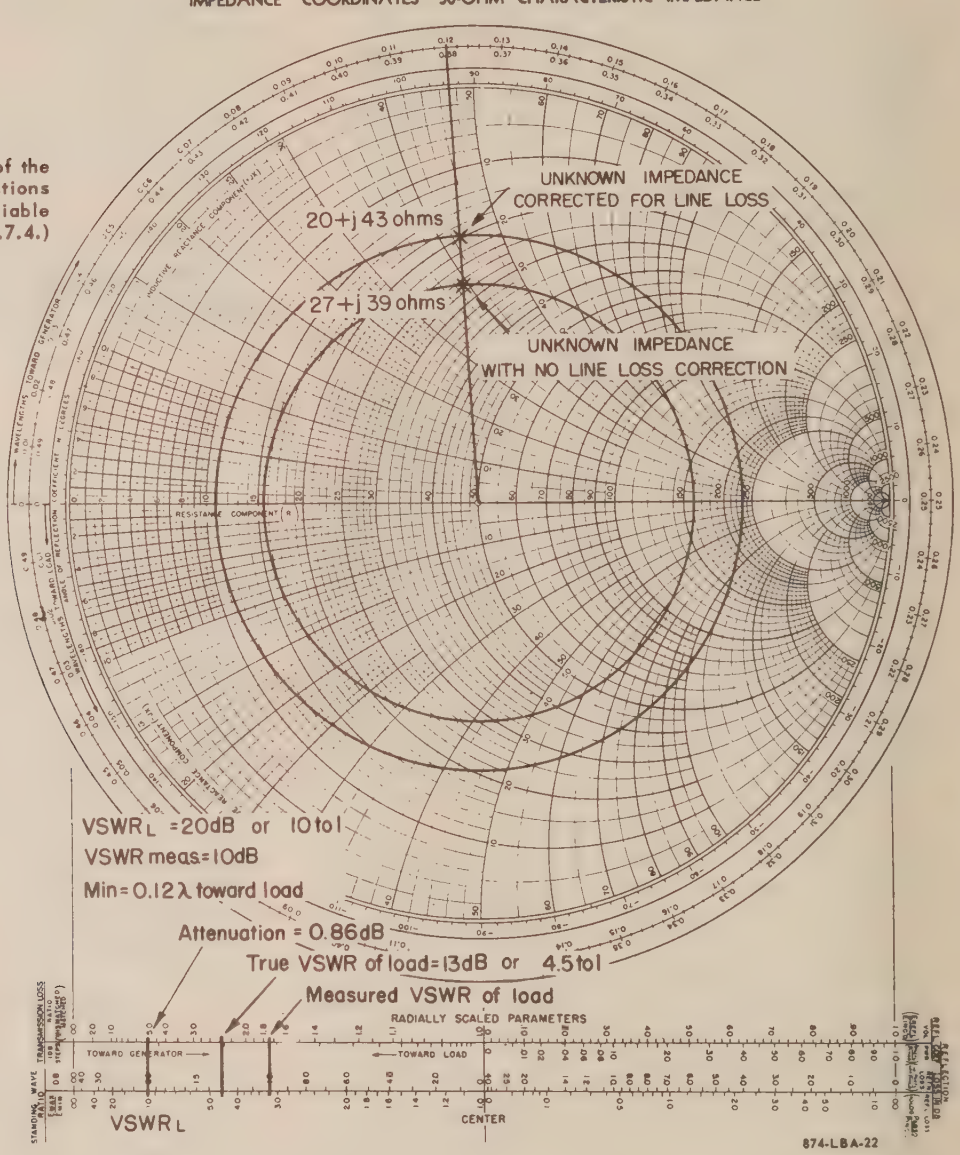


Figure 3-8. Example of the use of the Smith Chart for line length corrections when the line has an appreciable amount of loss. (See paragraph 3.7.4.)

voltage minimum at exactly the same position in the slotted-line as produced with the unknown connected. The lumped loss therefore has essentially the same effect in both cases. The actual or true VSWR in this case is:

$$\frac{1}{\text{VSWR}} \cong \frac{1}{(\text{VSWR})_M} - \frac{1}{(\text{VSWR})_C}$$

$$\text{VSWR} = \frac{(\text{VSWR})_M}{1 - \frac{(\text{VSWR})_M}{(\text{VSWR})_C}}$$

Where $(\text{VSWR})_C$ is the VSWR with the special short- or open-circuit.

3.7.6 OSCILLATOR FREQUENCY SHIFTS

In some cases, when the slotted-line is short- or open-circuited and the position of a voltage minimum is measured to determine the effective position of the unknown, errors can be caused by shifts in the oscillator frequency with the change in the load impedance between the short-circuited and loaded conditions. The effect can become more serious as the engtth of line between the load and the slotted line is increases. Oscillators which are tightly coupled to the line can have relatively large frequency shifts. The effect can be greatly reduced by the insertion of a pad, such as a Type 874-G10, 10-dB Pad, between the oscillator and the slotted line. If the resultant decrease in input cannot be tolerated, the oscillator tuning can be adjusted

to compensate for the frequency shift. The oscillator frequency can be measured and readjusted. Signal generators, in general, are loosely coupled, and the frequency shift is usually small.

3.7.7 HARMONICS

Another possible source of error in the measurement of high standing-wave ratios is the presence of harmonics in the wave traveling along the line. Harmonics can be generated by the driving oscillator or by a non-linear unknown such as a diode rectifier. The minima for the harmonics will not necessarily appear at the same points along the line or have the same relative amplitudes as the fundamental minima. Hence, a small harmonic content in the signal may produce a harmonic signal many times that of the fundamental at a minimum point. Therefore, if the detector will respond at all to harmonics, difficulty may be encountered. Superheterodyne receivers and the mixer rectifier detector, in general, have excellent harmonic rejection; but the tuned diode or video detector may not have a large amount of rejection for various harmonics because the tuning stub has higher-order resonances. When the diode detector is used for measurements of high VSWR's, and preferably even when a receiver is used, a good low-pass filter, such as the Type 874-F500L, -F1000L, -F2000L or -F4000L Low-Pass Filters, is required between the oscillator and the line to reduce the harmonics to an insignificant value. The Type DNT Detector is recommended when the VSWR is very high.

3.7.8 FREQUENCY MODULATION

The presence of appreciable frequency modulation on the applied signal may produce errors when the standing-wave ratio is very high. Frequency modulation is usually produced when a high-frequency oscillator is amplitude-modulated. The amount of frequency modulation for a given degree of amplitude modulation usually increases as the oscillator frequency approaches its upper limit. The Type 1209 Unit Oscillator and Type 1021-AU Signal Generator are satisfactory for modulated signal measurements on very high VSWR's at 50% modulation, up to about 750 MHz. At the higher frequencies, reasonably large errors are produced in measurements of standing-wave ratios of the order of 500 or 1000. At standing-wave ratios below 50, the error is usually negligible if the over-all line length is short. Square-wave modulation should be used to minimize frequency modulation. The Type 1264 Modulating Power Supply is recommended for use with the oscillators listed in Table 2-1.

This problem is minimized by employing a heterodyne detector as indicated in 3.7.2

3.8 MEASUREMENT OF 50-OHM COAXIAL LINE CIRCUITS

3.8.1 USE OF CONNECTING CABLE

In coaxial-line measurements, the VSWR on the line, the impedance seen looking into an unknown line, or the impedance at the far end of a line maybe needed. In measurements on antennas, either the VSWR on a line terminated in the antenna or the actual antenna impedance may be desired. However, in most cases it is not possible to connect the antenna directly to the slotted line and an intermediate length of cable or air line must be used. The line or cable should have a 50-ohm characteristic impedance. Lengths of Type 874-A2 or RG214/U Cable can be used for this purpose. The connecting line has no effect on the VSWR if it is a lossless, uniform line, hence the VSWR produced by the load is the same as that measured on the slotted line. *In practice, however, the connecting cable and comectors will not be absolutely uniform but will have small discontinuities which will have some effect on the VSWR. The uniformity of lengths of Type 874-L Air Line is much better than that of coaxial cable and should be used if possible, to obtain the most accurate results.* There is usually significant loss in the connecting cable. A correction can be made for it, as outlined in paragraph 3.7.4

3.8.2 MEASUREMENT OF VSWR ON A 50-OHM LINE

To determine the VSWR on a 50-ohm line terminated in the unknown, the following procedure can be used:

a. Set up the equipment and tune the detector, as outlined in paragraphs 2.3, 3.3, and 3.4.

b. Connect the unknown directly to the slotted line, if possible, or use lengths of 50-ohm air line or cable provided with constant-impedance connectors, such as Type 874. If the unknown is fitted with other than Type 874 Connectors, use one of the adaptors listed in Table 2-2.

c. Check the output from the detector at a voltage minimum and maximum and determine that the probe coupling is satisfactory, as outlined in paragraph 3.3. Only the voltage minima need be measured, if the width-of-minimum method can be used.

d. If the VSWR is less than 10, measure the relative output from the detector at several minima and maxima. Actually, only one minimum and one maximum need be measured, but because of the small variations in probe coupling along the line, greater accuracy can be obtained if several minima and maxima are averaged or if the probe coupling is calibrated, as outlined in paragraph 5.5. If the VSWR is greater than 10, use the heterodyne detector or the width-of-minimum method, outlined in paragraph 3.7.2 to determine the VSWR.

3.8.3 UNKNOWN IMPEDANCE CONNECTED AT THE END OF A 50-OHM LINE

To obtain the actual load impedance, use the following method:

a. Follow procedures a through d of paragraph 3.8.2.

b. Measure the position of the voltage minimum nearest the load end of the line.

c. Short-circuit the end of the line at the point of connection to the unknown. Use a very low inductance metal sheet or strap, or a Type 874-

WN3, -WNL Short Circuit, as described in paragraph 3.2. Then find the position of a voltage minimum on the line with the line shorted and record the scale reading corresponding to the probe position (refer to paragraph 3.7).

d. Determine the difference in position, ℓ, between the minimum measured with the line shorted, and the minimum measured with the unknown connected. Divide the result by the wavelength to obtain ℓ/λ. If several measurements are to be made at different frequencies on the same circuit, the over-all electrical line length between any point on the slotted line and the short circuit can be determined. Then the line needs to be short-circuited only once.

e. On the 50-ohm Smith Chart, determine the radius of the circle on which the impedance must lie from the scale labeled STANDING WAVE RATIO, located at the bottom of the chart. Draw a circle having this radius on the chart, with its center at the center of the chart. (Refer to paragraph 4.5.3) The transmission-line equations presented in paragraph 4.1 can be used in place of the Smith Chart. (The 50-ohm impedance version is considered here.)

f. Note whether the minimum found with the line shorted lies on the generator side or on the load side of the minimum found with the load connected. If the short-circuit minimum lies on the load side, travel from zero around the circle along the WAVELENGTHS TOWARD LOAD scale the number of wavelengths found in step d. If the minimum lies on the generator side, travel in the opposite direction along the WAVELENGTHS TOWARD GENERATOR scale. Draw a line from this point to the center of the chart.

g. Find the impedance in ohms of the unknown from the coordinates of the intersection of the line drawn in step f and the circle drawn in step e. If the admittance is desired, travel around the chart another 0.25 wavelength and draw another line to the center of the chart. The coordinates of the intersection of this line with the circle multiplied by 0.4 are the components of the admittance of the unknown in millimhos.

3.8.4 MEASUREMENT OF THE INPUT IMPEDANCE TO COAXIAL-LINE CIRCUITS

To measure the input impedance to a coaxial-line circuit, connect the circuit directly to the slotted line by means of a coaxial connector. Then use the procedure outlined in paragraph 3.8.3. In this measurement, the point in the connector at which the impedance is to be obtained must be specified, because the impedance may vary appreciably from one point to another in the connector. In many cases, it is advantageous to measure the impedance at the front face of the polystyrene bead in the unknown connector. (Refer to paragraph 3.2.) In order to determine the impedance at this point, the electrical distance from the insulator in the connector and the position of a voltage minimum on the slotted line must be found.

To determine the electrical distance, measure the physical distance between the two points in question and add 0.48 cm to the length obtained to account for the lower velocity of propagation in the insulators at the end of the slotted line.

Another more accurate method of determining the effective electrical distance is to short-circuit the end of the slotted line with a Type 874-WN, -WNL Short Circuit and then determine the position of a voltage minimum on the slotted line, as outlined in paragraph 4.4. The short circuit is made at the face of the bead in this unit.

Measure the VSWR and calculate the unknown impedance, as outlined in paragraph 3.8.3.

3.9 MEASUREMENTS ON COMPONENTS AND LUMPED CIRCUITS

3.9.1 PROCEDURES

The Type 874-LBB Slotted Line can be used to measure the impedance of components of all types. At high frequencies, this type of measurement is complicated by many factors, the most important of which generally are:

1. The position of the element with respect to ground, leads, and other circuit elements can have a large effect on the impedance of an element.
2. The reactances of leads used to connect the component to the measuring device, any leads which may be part of the component under test, and the stray capacitance of the measuring terminals and supplementary leads, may also appreciably affect the measurements.

To minimize the effects of the first difficulty, the component should be measured while mounted in the position in the circuit in which it is to be used, or under as similar conditions as possible. One method of measuring a component in position in a circuit is to connect it to the slotted line by means of a length of flexible cable or rigid coaxial line, as shown in Figure 3-9. The rigid line is preferred, as its characteristic impedance is more uniform. The impedance is measured, as outlined in paragraph 4.5.3. The line is short-circuited at its load end by one of the methods shown in Figure 3-1.

The supplementary leads used to connect the component to the end of the coaxial line should be as short as possible to minimize the effects of the lead and terminal reactances.

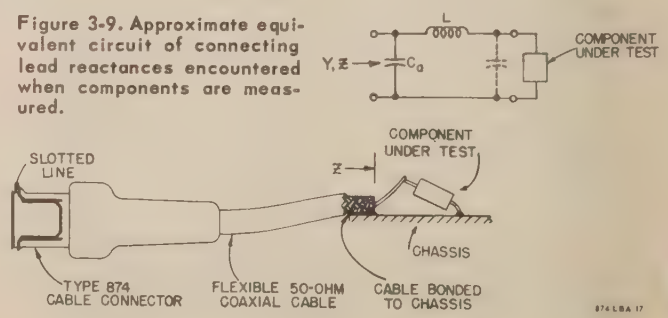


Figure 3-9. Approximate equivalent circuit of connecting lead reactances encountered when components are measured.

The leads referred to do not include those normally used to connect the unknown to the circuit. If the supplementary leads are short, the stray reactances can be considered as lumped into two elements: a shunt capacitance across the end of the line, and an inductance in series with the line, as shown in Figure 3-9. The lead and terminal reactances affect the measured impedance Z_M, as can be seen from the equivalent circuit in the figure. In order to determine the actual impedance of the unknown, the measured impedance should be corrected for the effects of the lead and terminal reactances, using the following equations:

$$R_X = \frac{R_M}{D}$$

$$X_X = \frac{X_M\left(1 - \frac{X_M}{X_A}\right) - \frac{R_M^2}{X_A}}{D} - X_L$$

where

$$D = \left(1 - \frac{X_M}{X_A}\right)^2 + \left(\frac{R_M}{X_A}\right)^2$$

$$X_A = -\frac{1}{\omega C_A} \text{ ohms}$$

$$X_L = \omega L \text{ ohms}$$

where L is the magnitude of the lead inductance in henrys and C_A is the magnitude of the shunt capacitance in farads.

The magnitudes of the lead and terminal reactances can be determined from measurements of the reactance seen with the leads short-circuited by a low-inductance copper sheet at the point of connection to the unknown, and the reactance seen with the leads open-circuited at the point of connection to the unknown. The inductive reactance is measured when the leads are short-circuited and the capacitive reactance is measured when the leads are open-circuited. For this approximation to hold, the lead-capacitive reactance should be greater than five times the lead-inductive reactance.

A somewhat better approximation can be made if the lead capacitance is assumed to be distributed between the two ends of the leads, as shown by the dotted capacitor of Figure 3-9. The ratio of the two capacitances can be estimated from the physical configuration of the circuit.

An even better approximation can be made when the leads are reasonably long, if the inductance and capacitance are assumed to be uniformly distributed and the leads are treated as a section of transmission line. The characteristic impedance, Z_o, of this line and the tangent of the electrical length, tan θ, are related to the short- and open-circuit impedances, Z_{OC} and Z_{SC}, by the expressions:

$$Z_o = \sqrt{Z_{OC} Z_{SC}}$$

$$\tan\theta = \sqrt{\frac{Z_{SC}}{Z_{OC}}} = \frac{X_{SC}}{Z_o}$$

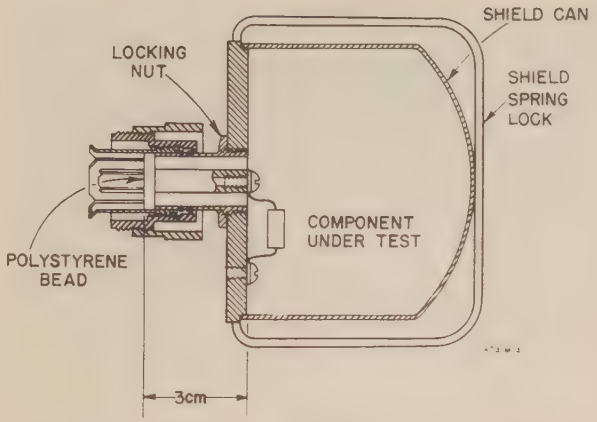


Figure 3-10. Sketch of the Type 874-ML Component Mount.

The equation in paragraph 4.1, or the Smith Chart, can be used to correct the measured impedance for the effect of the equivalent section of transmission line. If a Smith Chart designed for lines having a 50-ohm impedance is used, the measured values should be divided by $\frac{Z_o}{50}$ before entering the chart and the resultant corrected impedance multiplied by $\frac{Z_o}{50}$. In most cases the capacitance is not uniformly distributed but the approximation usually gives reasonably accurate results. A normalized Smith Chart is better suited to this application.

In most cases more accurate measurements can be made by use of the Type 874-ML Component Mount, shown in Figure 3-10, on which the component or lumped circuit can be mounted. The end of the center conductor of a section of air line is used as the ungrounded terminal, and the outer conductor is extended in the form of a disk for a ground plane. The line can be short-circuited at the terminal by means of a very low inductance disk (supplied) or the mount can be disconnected and replaced by a Type 874-WN3 Short-Circuit Termination Unit. The distance from the front face of the polystyrene bead in the connector mount is located 3 cm away from the ground-plane surface; hence, the termination unit referred to places a short-circuit effectively at the ground-plane surface when it is substituted for the component mount.

A correction must be made for the reactance of supplementary leads, as previously outlined.

To remove the coaxial-line section from the ground plate or to mount it on another one, loosen the locking nut. It can then be installed in any other plate if a 3/4-27 tapped hole is provided.

3.9.2 EXAMPLE OF MEASUREMENT OF A 200-OHM RESISTOR AT 600 MHz.

In this case, the resistor is mounted on a Type 874-ML Component Mount, shown in Figure 3-10, which is connected to the slotted line. A block diagram of the setup is shown in Figure 2-1. The stub is tuned with

slotted line terminated with Type 874-W50B or -W50BL, as indicated in paragraph 3.4. The unknown is connected and the input power is adjusted to operate the diode within the square-law range. Averages of several VSWR readings are taken to minimize the effect of the variation in probe coupling along the line, and an average reading of 3.16 is obtained. Position of the voltage minimum nearest load was 40.25 cm.

The component mount is then disconnected, the Type 874-WN3 Short Circuit is connected to the slotted line, and the position of a voltage minimum is located. The position of the minimum nearest the load is found to be at 51.20 cm. Therefore,

VSWR = 3.16

$$\frac{\ell}{\lambda} = \frac{51.20 - 40.25}{50} = 0.219 \text{ wavelength}$$

The measured resistance and reactance, calculated by the use of the Smith Chart, are:

R_M = 118 ohms; X_M = -66 ohms.

In this case, the impedance directly across the ends of the resistor is needed. However, the resistor is connected to the mount by means of its own leads, which affect the measurements. Since it is not desirable to clip the leads at the ends of the resistor to measure the lead reactances, the resistor is removed and identical leads are substituted. The position of the minimum on the line is determined with the leads open-circuited and is found to be 39.90 cm. The ends of the leads are short-circuited by spot-soldering a copper sheet about three inches in diameter to the ends of the leads and the minimum position is found again. In this case it is at 32.95 cm.

The short-circuit reactance, X_{SC}, calculated from the Smith Chart, is +57 ohms. The open-circuit reactance, X_{OC}, is -330 ohms. The actual impedance appearing across the resistor terminals is then calculated by

R_M = 118 ohms

X_M = -66.0 ohms

$X_L = X_{SC}$ = +57 ohms

$X_A = X_{OC}$ = -330 ohms

$$D = \left(1 - \frac{-66}{-330}\right)^2 + \left(\frac{118}{330}\right)^2 = 0.768$$

$$R_X = \frac{118}{0.768} = 154 \text{ ohms}$$

$$X_X = \frac{-66\left(1 - \frac{-66}{-330}\right) - \frac{118^2}{-330}}{0.768} = \frac{-57}{0.768} = -72.2 \text{ ohms}$$

The measured resistance is less than the dc value of 200 ohms, due to the shunt capacitance of the resistor itself.

3.10 OPERATION AT FREQUENCIES BELOW 300 MHz

Since the probe travel is only 50 cm, it will not always be possible to measure both a voltage minimum and maximum on the line at frequencies below 300 MHz, as the range of travel of the probe is one-half wavelength at 300 MHz. At frequencies below 150 MHz, where the line is less than a quarter of a wavelength, it will never be possible to measure both a voltage maximum and minimum on the line directly. If both a voltage minimum and maximum do not appear on the line at frequencies above 150 MHz, additional lengths of Type 874-L30, -L10, -L30L, and -L10L Air Lines can be inserted between the line and the load until both a minimum and a maximum do appear. Of course, if the VSWR is greater than 10, only the minimum need appear on the slotted section of line, because the measurement can be made by the width-of-minimum method.

At frequencies below 150 MHz, lengths of air line can be inserted between the line and the load until either a minimum or maximum can be measured. Sections of air line are then *transferred* to the other side of the slotted line, that is, between the line and the generator, until the maximum or minimum appears and can be measured. The sections are transferred, rather than removed, to keep the load on the oscillator and, hence, the relative voltage amplitude on the line, constant.

A somewhat better solution is to use two slotted lines and add sections of air line between them or between one of them and the load until a minimum appears on one line and a maximum on the other. The probes are set at the respective maximum and minimum and the outputs from the detector and the position of the probe at the minimum are recorded. A Type 874-W50B and -W50BL Termination Unit is then connected to the end of the line and the outputs of the two detectors again recorded. Since the voltage is constant all along the line with the termination connected, the probe couplings in this case are proportional to the outputs if the detector is linear. If the detector is square-law, the probe couplings are proportional to the square roots of the outputs. The outputs observed with the load connected can then be corrected for any difference in coupling. This calibration corrects for differences in probe penetration, differences in probe couplings, and differences in sensitivity of the detectors.

Alternately the slotted-lines may be connected together directly and the probes adjusted to produce the same output with the line terminated with the Type 874-W50B or -W50BL. The standing-wave pattern is observed first with one line and continued with the next by switching the detector connection.

The Type 874-D20L Stub will tune the diode rectifier down to 275 MHz. The Type 874-D50L Stub will tune down to 125 MHz. Additional lengths of air line can be inserted in series or in shunt, using a Type 874 Tee for operation at lower frequencies. With the long stub in place, smoother operation of the carriage is obtained if the whole slotted line is tilted slightly forward to make the stub almost vertical.

3.11 USE OF THE ADJUSTABLE SCALE AND THE VERNIER DRIVE

The scale of the Type 874-LBB Slotted Line is adjustable and can be locked in position, permitting the choice of a convenient reference point.

This feature together with the Type 874-LV Vernier Drive enables simple and accurate length measurements.

For example, when measuring the distance between two minima (Figure 3-11), find the first minimum and set the scale to have a convenient full division in front of the pointer (A), then set the pointer to the full division closest to the second minimum (B) and use the vernier drive to reach the minimum. The distance desired is then AB plus (or minus) the distance traveled by the vernier drive.

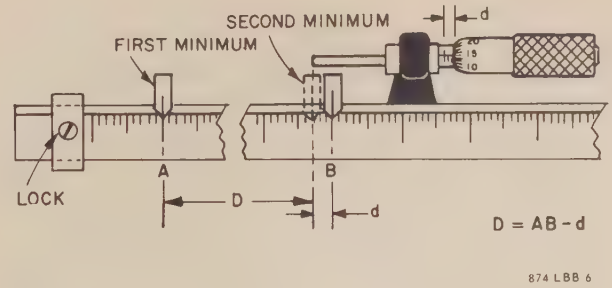


Figure 3-11. An accurate way to find the distance between two minima.

SECTION 4 PRINCIPLES OF OPERATION

4.1 TRANSMISSION LINE CHARACTERISTICS

4.1.1 CHARACTERISTIC IMPEDANCE

A coaxial transmission line has uniformly distributed inductance and capacitance, as shown in Figure 4-1. The series resistance due to conductor losses and the shunt resistance due to dielectric losses are also uniformly distributed. The square root of the ratio of the inductance-per-unit-length, L, to the capacitance-per-unit-length, C, is defined as the characteristic impedance, Z_o, of the line.

$$Z_o = \sqrt{\frac{R + j\omega L}{G + j\omega C}} = \sqrt{\frac{L}{C} \times \frac{1 - j\frac{R}{\omega L}}{1 - j\frac{G}{\omega C}}}$$

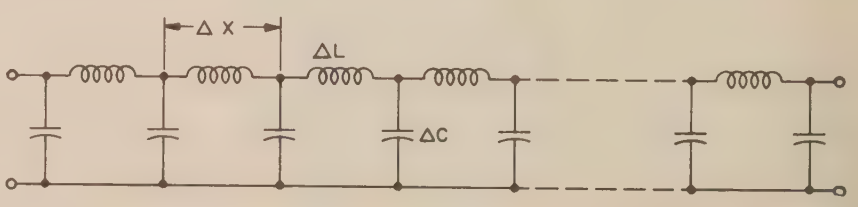
where:

L = the inductance-per-unit-length in henrys,
C = the capacitance-per-unit-length in farads,
R = the series-resistance-per-unit-length in ohms, and
G = the shunt-conductance-per-unit-length in mhos.

When line losses are low (or when $\frac{R}{L} = \frac{G}{C}$) and the rf skin effect depth is much smaller than the diameter tolerances, the following approximation is valid:

$$Z_o \approx \sqrt{\frac{L}{C}}$$

As frequency decreases, the path of the average current flow tends to move away from the surfaces of the conductors. It moves toward the center of the inner conductor and away from the inner surface of the outer conductor. Thus, the effective diameters are shifted (in opposite directions), thereby causing a slight increase in the ratio which determines the characteristic impedance. The extent of this shift varies with the material used for the conductors and is least with a



900-LB25

Figure 4-1. Distribution of inductance and capacitance along a transmission line.

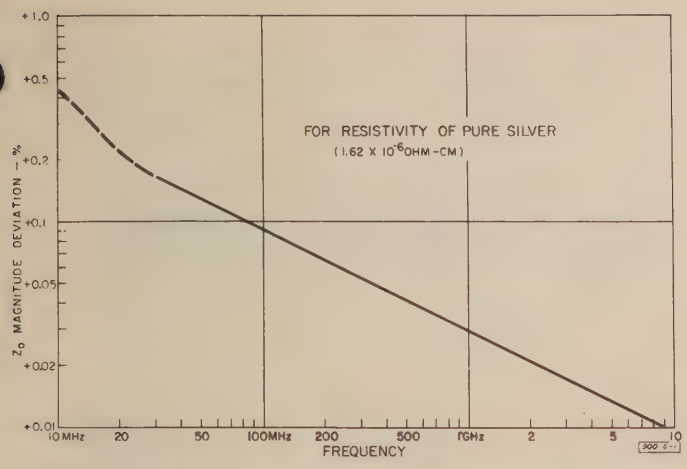


Figure 4-2. Skin-effect error as a function of frequency.

conductor such as silver. In silver this effect is enough to cause a change of 0.1% at 100 MHz; see Figure 4-2.

The characteristic impedance of a coaxial line derives directly from the diameters of the conductors, the ratio that these diameters bear to one another, their respective concentricity, and the dielectric constant of the medium separating them. Thus, for concentric coaxial lines in general, the expression is:

$$Z = \frac{A}{\sqrt{\epsilon}} \log_e \frac{a}{b}$$

where:

a = inner diameter of outer conductor

b = outer diameter of inner conductor

ϵ = dielectric constant

$$A = \frac{2c}{10^9} = 59.9585$$

c = velocity of light, cm/sec

The dielectric constant of air under standard laboratory conditions is 1.0007.

The accuracy of the characteristic impedance, therefore, is controlled by the precision with which the inner and outer conductors can be machined. Furthermore, the constancy of impedance depends in turn upon the ability of the fabrication process to maintain uniform size and to preserve straightness throughout, since deviations result in impedance variations.

The uniformity of the impedance along the line is also dependent upon the concentricity of the conductors. An important factor bearing upon this consideration is sag occurring in the center conductor. The characteristic impedance of a coaxial transmission line with an eccentric inner conductor is given by the following:

$$Z_o = \frac{A}{\sqrt{\epsilon}} \cosh^{-1}\left[\frac{b}{2a}\left(1 - 4\frac{e^2}{b^2}\right) + \frac{a}{2b}\right],$$

where:

e = amount of eccentricity of the center conductor.

4.1.2 WAVE PROPAGATION

As with all transmission-line types, the purpose of coaxial line is to carry energy from a source to a load. The efficiency with which it performs this function at uhf and above is dependent upon (among other things) the mode in which it propagates electromagnetic-wave energy. Such modes of propagation can best be described in terms of their electrical and magnetic field patterns within the line.

A coaxial transmission line may provide the means for more than a single mode of propagation. Commonly, the dominant mode is that in which both electrical and magnetic field components of the wave lie entirely in planes transverse to the direction of propagation (see Figure 4-3). The wave is therefore called a transverse electromagnetic (TEM) wave. There is no longitudinal component of the field in this mode, as in rectangular waveguide. Thus, this mode is broadband and has no cutoff frequency.

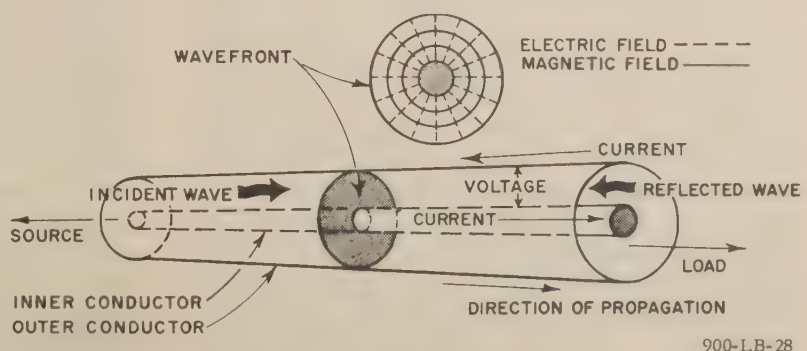


Figure 4-3. TEM-mode field pattern in coaxial transmission line.

4.1.3 VELOCITY OF PROPAGATION

In subsequent paragraphs, transmission-line behavior will be discussed in terms of electromagnetic waves propagating along the line. The waves travel with a velocity, v, which depends on L and C in the following manner:

$$v = \frac{1}{\sqrt{LC}}$$

In an evacuated line, the dielectric constant is unity and the velocity of propagation is equal to the velocity of light, c, (2.997925×10^{10} cm/sec). If the effective dielectric constant, ϵ, is greater than unity, the velocity of propagation will be the velocity of light divided by the square root of the effective dielectric constant:

$$v = \frac{c}{\sqrt{\epsilon}}$$

The relationship between frequency, f, and wavelength, λ, in the transmission line, if the dielectric is air, is

$$\lambda = \frac{2.99687 \times 10^{10}}{f} \text{ cm/sec}$$

if λ is in centimeters and f is in hertz.

4.1.4 TRAVELING AND STANDING WAVES

The performance of a transmission line having a uniform characteristic impedance can be explained in terms of the behavior of the electromagnetic wave that travels along the line from the generator to the load, where all or a portion of it may be reflected, with or without a change in phase, as shown in Figure 4-4. The reflected wave travels in the opposite direction along the line, back toward the generator. The phases of these waves are retarded linearly 360° for each wavelength traveled.

The wave traveling from the generator is called the incident wave, and the wave traveling toward the generator is called the reflected wave. The combination of these two traveling waves produces a stationary interference pattern which is called a standing wave. The maximum amplitude of the standing wave occurs when the incident and reflected waves are in phase or when they are an integral multiple of 360° out of phase. The minimum amplitude occurs when the two waves are 180°, or an odd integral multiple thereof, out of phase. The amplitude of the standing wave at other points along the line is the vector sum of incident and reflected waves. Successive minima and maxima are spaced, respectively, a half wavelength along the line.

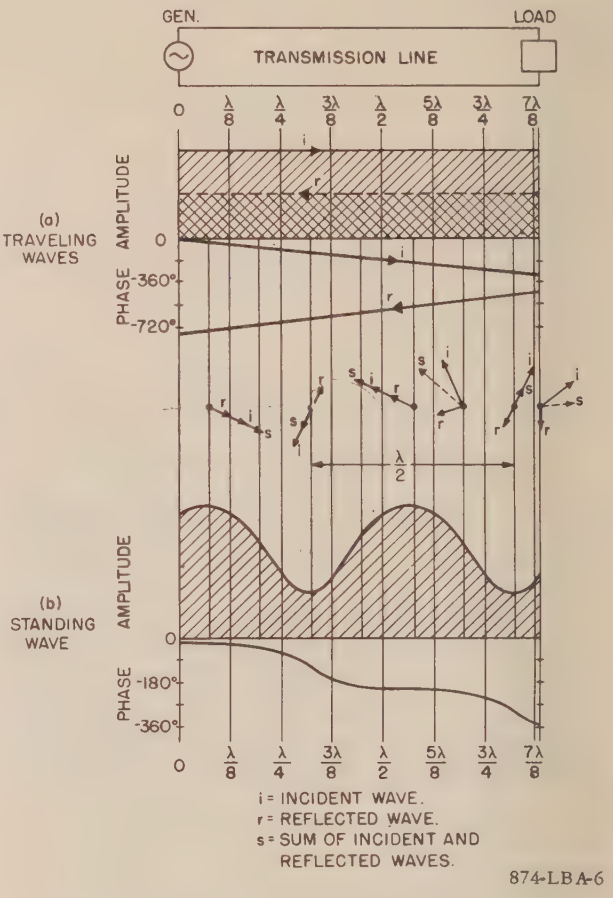


Figure 4-4. Variations in the amplitude and phase of incident and reflected waves along a transmission line with a 3:1 mismatch condition. Vector combination of incident and reflected waves at various points along the line and resultant standing wave are shown.

The magnitude and phase of the reflected wave at the load, relative to the incident wave, are functions of the load impedance. For instance, if the load impedance is the same as the characteristic impedance of the transmission line, the incident wave is totally absorbed in the load and there is no reflected wave. On the other hand, if the load is lossless, the incident wave is always completely reflected, with no change in amplitude but with a change in phase.

A traveling electromagnetic wave actually consists of two component waves: a voltage wave and a current wave. The ratio of the magnitude and phase of the incident voltage wave, E_i, to the magnitude and phase of the incident current wave, I_i, is always equal to the characterisitc impedance, Z_o. The reflected

waves travel in the opposite direction from the incident waves, and consequently the ratio of the reflected voltage wave, E_r, to the reflected current wave, I_r, is $-Z_o$. Since the characteristic impedance in most cases is practically a pure resistance, the incident voltage and current waves are in phase with each other, and the reflected voltage and current waves are 180° out of phase.

$$\frac{E_i}{I_i} = Z_o$$

$$\frac{E_r}{I_r} = -Z_o$$

These equations are valid at all points along the line.

The magnitude and phase of the reflected voltage wave, E_r, relative to the incident wave, E_i, at the load is called the reflection coefficient, Γ, which can be calculated from the expression

$$\Gamma = \frac{Z_x - Z_o}{Z_x + Z_o} = \frac{Y_o - Y_x}{Y_o + Y_x}$$

$E_r = E_i\Gamma$ at the load

$I_r = -I_i\Gamma$ at the load

where Z_x and Y_x are the complex load impedance and admittance, and Z_o and Y_o are the characteristic impedance and admittance of the line $\left(Y_o = \frac{1}{Z_o}\right)$.

4.2 VOLTAGE AND CURRENT DISTRIBUTION

If the line is terminated in an impedance equal to the characteristic impedance of the line, there will be no reflected wave, and $\Gamma = 0$. The voltage and current distributions along the line for this case are shown in Figure 4-5.

If the line is open-circuited at the load, the voltage wave will be completely reflected and will undergo no phase shift on reflection, $(Z_x = \infty)$, while the current wave will also be completely reflected but will undergo a 180° phase shift on reflection, as shown in Figure 4-6. If the line is short-circuited, the current and voltage roles are interchanged, and the impedance pattern is shifted $\lambda/4$ along the line. The phase shifts of the voltage and current waves on reflection always differ by 180°, as the reflected wave travels in the opposite direction from the incident wave. A current maximum, therefore, always occurs at a voltage minimum, and vice versa.

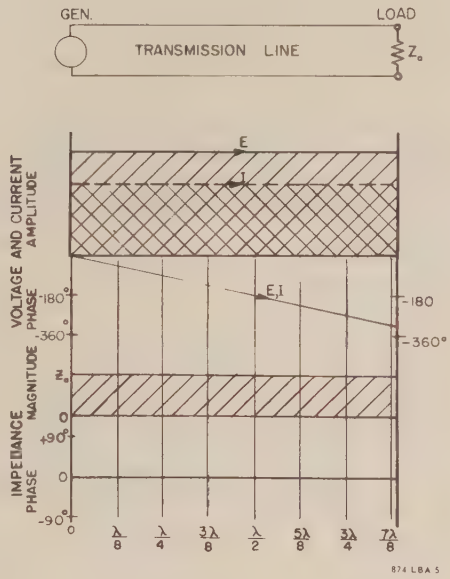


Figure 4-5. Voltage and current waves along a transmission line terminated in its characteristic impedance. Note the absence of reflected waves and that the impedance is constant and equal to the characteristic impedance at all points along the line.

The voltage at a maximum of the standing-wave pattern, E_{max}, is $|E_i| + |E_r|$ or $|E_i|\ (1 + |\Gamma|)$ and at a minimum, E_{min}, is $|E_i| - |E_r|$ or $|E_i| \times (1 - |\Gamma|)$. The ratio of the maximum to minimum voltages, which is called the voltage standing-wave ratio, VSWR, is

$$VSWR = \frac{E_{max}}{E_{min}} = \frac{1 + |\Gamma|}{1 - |\Gamma|}$$

The standing-wave ratio is frequently expressed in decibels or percent

$$VSWR \text{ in dB} = 20 \log_{10} \frac{E_{max}}{E_{min}}$$

$$VSWR \text{ in } \% = 100\left(\frac{E_{max}}{E_{min}} - 1\right)$$

4.3 LINE IMPEDANCES

At any point along a uniform lossless line, the impedance seen looking towards the load, Z_p, is the ratio of the complex voltage to the complex current at that point. It varies along the line in a cyclical manner, repeating each half wavelength of the line, as shown in Figure 4-6.

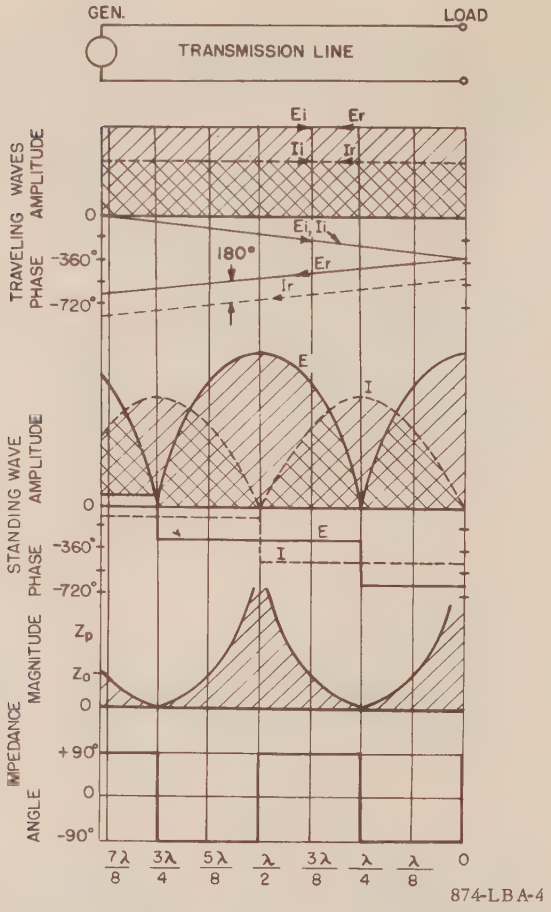


Figure 4-6. Voltage and current waves along a transmission line terminated in an open-circuit. Note that the minima of the voltage waves occur at the maxima of the current waves, and vice versa, and that the separation of adjacent minima for each wave is a half wavelength. The variation in the magnitude and phase angle of the impedance is also shown.

At a voltage maximum on the line, the incident and reflected voltage waves are in phase, and the incident and reflected current waves are 180° out of phase with each other. Since the incident voltage and incident current waves are always in phase (assuming Z_o is a pure resistance), the effective voltage and current at the voltage maximum are in phase and Z_p at that point is pure resistance. At a voltage maximum, Z_p is equal to the characteristic impedance multiplied by the standing-wave ratio.

$$Z_p = Z_o \times VSWR$$

At a voltage minimum, the two voltage waves are opposing and the two current waves are aiding. Again the effective impedance is a pure resistance and is equal to the characteristic impedance of the line divided by the standing-wave ratio.

$$Z_p = \frac{Z_o}{VSWR}$$

The impedance, Z_p, at any point along the line is related to the load impedance by the expression

$$Z_p = Z_o\left(\frac{Z_x + jZ_o\tan\theta}{Z_o + jZ_x\tan\theta}\right)$$

where

Z_o = characteristic impedance,

Z_x = complex load impedance,

$\theta = \frac{2\pi\ell_e}{\lambda}, = \beta\,\ell_e$

ℓ_e = electrical length of line between point p and load, $\ell\sqrt{\epsilon}$

ℓ = physical length.

Thus, if ℓ_e is in cm,

$\theta = 12 \times f_{GHz} \times \ell_e$, degrees.

In Figure 4-7, point p is shown at a voltage minimum. However, the expressions above are valid for any location of point p on the line.

Conversely, the load impedance, Z_x, can be determined if the impedance, Z_p, at any point along a lossless line is known. The expressions relating the impedances are:

$$Z_x = Z_o\left(\frac{Z_p - jZ_o\tan\theta}{Z_o - jZ_p\tan\theta}\right)$$

The load impedance can be calculated from a knowledge of the VSWR present on the line and the position of a voltage minimum with respect to the load, since the impedance at a voltage minimum is related to the VSWR. The expression for the load impedance in

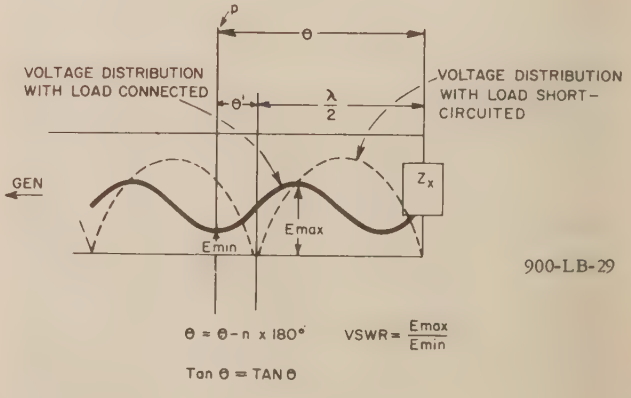


Figure 4-7. Voltage variation along a transmission line with a load connected, and with the line short-circuited at the load end.

terms of the VSWR, S, and the electrical distance, θ, between the voltage minimum and the load, is:

$$Z_x = Z_o \left(\frac{1 - jS \tan\theta}{S - j\tan\theta} \right)$$

$$= Z_o \left(\frac{2S - j\left[S^2 - 1\right] \sin 2\theta}{\left[S^2 + 1\right] + \left[S^2 - 1\right] \cos 2\theta} \right)$$

Since in a lossless line the impedance is the same at half-wavelength intervals along the line, θ' can be the electrical distance between a voltage minimum and any multiple of a half-wavelength from the load (see Figure 4-7). Of course, if the half-wavelength point used is on the generator side of the voltage minimum located with the load connected, θ' will be negative. The points corresponding to half-wavelength distances from the load can be determined, with the line short-circuited at the load, from the positions of the voltage minima on the line. The minima will occur at multiples of a half-wavelength from the load.

If the VSWR is greater than 10 tan θ, the following approximation gives good results:

$$R_x \cong \frac{Z_o}{S \cos^2 \theta}$$

$$X_x \cong -Z_o \tan \theta$$

Corresponding general equations in admittance terms are:

$$Y_p = Y_o \left(\frac{Y_x + jY_o \tan\theta}{Y_o + jY_x \tan\theta} \right)$$

$$Y_x = Y_o \left(\frac{Y_p - jY_o \tan\theta}{Y_o - jY_p \tan\theta} \right)$$

4.4 DETERMINATION OF THE LOAD IMPEDANCE FROM THE STANDING-WAVE PATTERN

The load impedance can be calculated from a knowledge of the VSWR present on the line and the position of a voltage minimum with respect to the load, since the impedance at a voltage minimum is related to the VSWR. An expression for the load impedance in terms of the VSWR and the electrical distance, θ, between the voltage minimum and the load is readily obtained.

$$Z_X = Z_o \cdot \frac{1 - j\,(\mathrm{VSWR}) \tan\theta}{\mathrm{VSWR} - j \tan\theta}$$

$$= Z_o \cdot \frac{2(\mathrm{VSWR}) - j\left[(\mathrm{VSWR})^2 - 1\right] \sin 2\theta}{\left[(\mathrm{VSWR})^2 + 1\right] + \left[(\mathrm{VSWR})^2 - 1\right] \cos 2\theta}$$

Since in a lossless line the impedance is the same at half-wavelength intervals along the line, θ can be the electrical distance between a voltage minimum and any multiple of a half-wavelength from the load (see Figure 4-7). Of course, if the half-wavelength point used is on the generator side of the voltage minimum located with the load connected, θ will be negative. The points corresponding to half-wavelength distances from the load can be determined by short-circuiting the line at the load and noting the positions of the voltage minima on the line. The minima will occur at multiples of a half-wavelength from the load.

If the VSWR is greater than 10 tan θ, the following approximation of the previous equation gives good results:

$$R_X \cong \frac{Z_o}{\mathrm{VSWR} \cos^2 \theta}$$

$$X_X \cong -Z_o \tan \theta$$

4.5 SMITH CHART

4.5.1 GENERAL

The calculation of the impedance transformation produced by a length of transmission line using the equations previously presented can be time consuming. Mr. P. H. Smith [1] has devised a chart, shown in Figure 4-8, which simplifies these calculations. In this chart the circles whose centers lie of the resistance component axis correspond to constant values of resistance. The arcs of circles whose centers lie on an axis perpendicular to the resistance axis correspond to constant values of reactance. The chart covers all values of impedance from zero to infinity. The position of a point corresponding to any given complex impedance can be found from the intersection of the resistance and reactance coordinates corresponding to the resistive and reactive components of the unknown impedance.

As the distance from the load is increased or decreased, the impedance seen looking along the line toward a fixed unknown will travel around a circle with its center at the center of the chart. The angular movement around the circle is proportional to the electrical displacement along the line. One complete traverse of the circle will be made for each half-wavelength of travel. The radius of the circle is a function of the VSWR.

[1] Smith, P. H., *Electronics*, Vol 17, No. 1, pp 130-133, 318-325, January 1944.

4.5.2 CALCULATION OF IMPEDANCE AT ONE POINT FROM THE IMPEDANCE AT ANOTHER POINT ON A LINE

If the impedance at one point of a line, say at a point p, is known and the impedance at another point a known electrical distance away (for instance, at the load) is desired, the problem can be solved using the Smith Chart in the following manner: First, locate the point on the chart corresponding to the known impedance, as shown in Figure 4-8. (For example, assume that Z_P = 20 + j25 ohms.) Then, draw a line from the center of the chart through Z_P to the outside edge of the chart. If the point at which the impedance is desired is on the load side of the point at which the impedance is known, travel along the WAVELENGTHS TOWARD LOAD scale, from the intersection of the line previously drawn, a distance equal to the electrical distance in wavelengths between the point at which the impedance is known and the point at which it is desired. If the point at which the impedance is desired is on the generator side of the point at which the impedance is known, use the WAVELENGTHS TOWARD GENERATOR scale. (In this example, assume that the electrical distance is 0.11 wavelength toward the load.) Next, draw a circle through Z_P with its center at the center of the chart, or layout on the last radial line drawn a distance equal to the distance between Z_P and the center of the chart. The coordinates of the point found are the resistive and reactive components of the desired

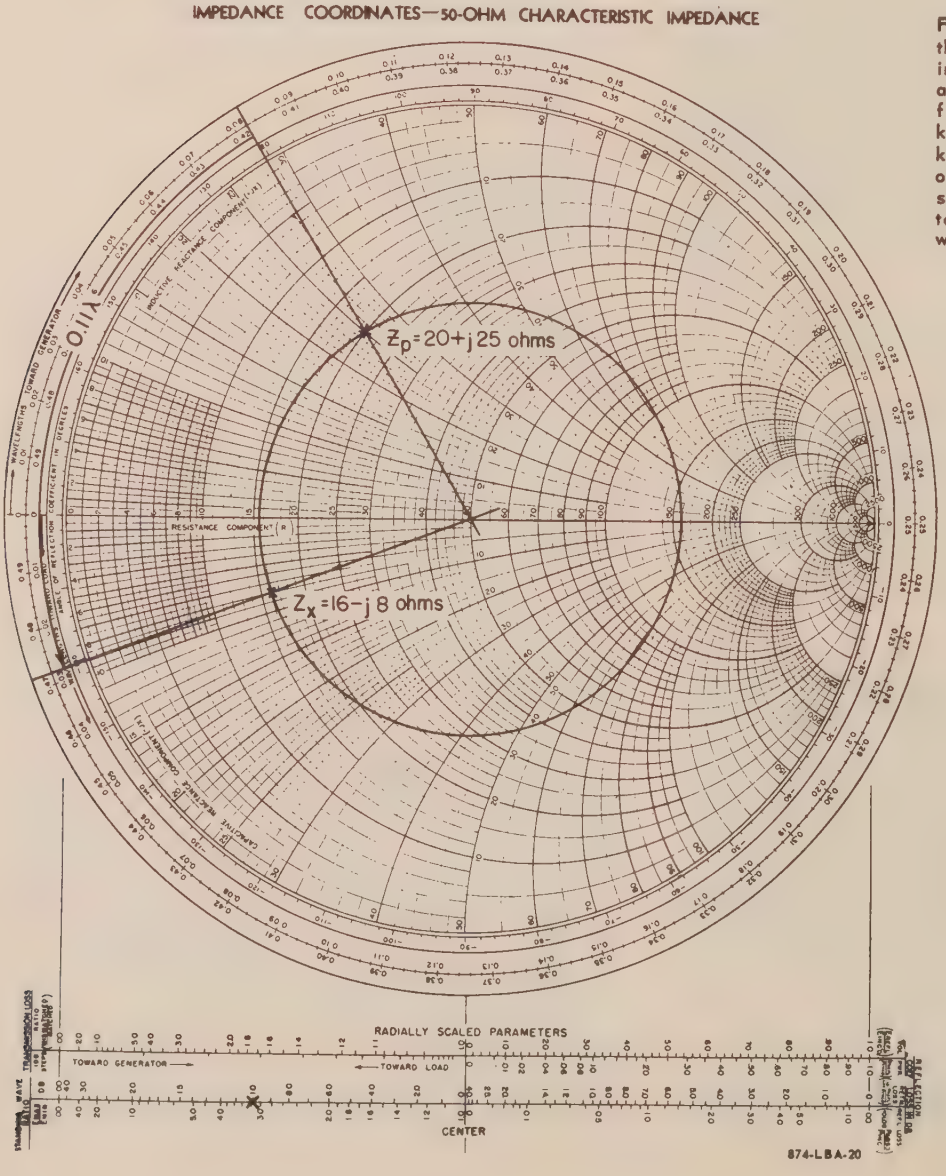


Figure 4-8. Illustration of the use of the Smith Chart for determining the impedance at a certain point along a line when the impedance a specified electrical distance away is known, In the example plotted, the known impedance, Z_p, is 20 + j25 ohms and the impedance, Z_x, is desired at a point 0.11 wavelength toward the load from the point at which the impedance is known.

impedance. (In the example chosen, the impedance is 16 - j8 ohms.)

The VSWR on the line is a function of the radial distance from the point corresponding to the impedance, to the center of the chart. To find the VSWR, lay out the distance on the STANDING WAVE RATIO scale located at the bottom of the chart, and read the VSWR as a ratio, $\frac{E_{MAX}}{E_{MIN}}$, or in dB on the appropriate scale. (In the example of Figure 4-8, the VSWR is 3.2 or 10.1 dB.)

4.5.3 CALCULATION OF IMPEDANCE AT THE LOAD FROM THE VSWR AND POSITION OF A VOLTAGE MINIMUM

In impedance measurements in which the voltage standing-wave pattern is measured, the impedance at a voltage minimum is a pure resistance having a magnitude of $\frac{Z_o}{VSWR}$. Plot this point on the resistance component axis and draw a circle having its center at the center of the chart drawn through the point. The impedance at any point along the transmission line must lie on this circle. To determine the load impedance, travel around the circle from the original point an angular distance on the WAVELENGTHS TOWARD LOAD scale equal to the electrical distance, expressed as a fraction of a wavelength, between the voltage minimum and the load (or a point a half-wavelength away from the load, as explained in paragraph 4.4). If the half-wave point chosen lies on the generator side of the minimum found with the load connected, travel around the chart in the opposite direction, using the WAVELENGTHS TOWARD GENERATOR scale. The radius of the circle can be determined directly from the VSWR, expressed as a ratio, or, if desired, in decibels by use of the scales labeled STANDING WAVE RATIO, located at the bottom of the chart.

4.6 SLOTTED LINES

4.6.1 GENERAL

The most accessible property of a transmission line, in measurement terms, is VSWR. A common method of measuring VSWR amplitude and phase is by observation of the standing-wave pattern in the line. This is accomplished by means of a narrow, longitudinal slot cut in the outer conductor of a standardized section of coaxial line, so that interior rf fields can be sampled with a movable probe inserted through the slot. The probe is part of an assembly mounted on a carriage capable of moving over the entire length of the slot on an accurately calibrated track. Within the probe assembly is an adjustable, thin rod that penetrates the line to extract the rf sample. Ideally, the probe is part of a tuned structure, so that it will provide a maximum pickup, which is detected by a microwave diode, an integral part of the assembly. The output of the diode is an audio voltage directly proportional to the rf power sampled, provided that the diode is operated in the square-law region of its response characteristic.

The output of the probe assembly must then be fed to a calibrated amplifier-indicator to measure VSWR magnitude. In addition, phase information (with respect to a fixed reference plane) can be determined from the position of the probe, when it is in a minimum of the standing-wave pattern. The reflection coefficient can be calculated from VSWR measurements, as can impedance. Impedance or admittance data can also be plotted by use of the Smith chart.

Desirable characteristics of a good slotted line include the following:

1. The coaxial line must be uniform, with straight and concentric conductors, so that it does not itself introduce reflections.
2. It should possess a true coaxial cross section, free of step discontinuities.
3. It should be terminated at the measurement end with a precision coaxial connector possessing dimensional and electrical uniformity nearly identical to that of the line.
4. The line of motion of the tip of the probe and the axis of the line must all be accurately parallel.
5. The instrument must have mechanical rigidity.
6. Wear of moving parts in the carriage must be low.

4.6.2 SLOTTED-LINE ERRORS

There are certain inherent errors in a slotted line which must be considered. The instrument errors may be neglected in many applications, but they must be taken into account when accuracies of a few percent or less are desired.

Certain rather obvious operational precautions are required, even for less-stringent accuracies. For example, the signal source must be stable in both amplitude and frequency and present a low harmonic level, all connectors must be tight and properly mated, and the response law of the detector must be accurately known.

Some of the more common sources of inherent instrument error are:

1. Residual VSWR.
2. Probe effects.
3. Losses.

The design of the Type 874-LBB Slotted Line, to a very great degree, either compensates directly for these errors or provides operator adjustments to overcome them. Still further reductions can be achieved by the precision calibration procedures given in Section 5.

Residual VSWR. The residual VSWR of a slotted line is that measured when the line is terminated in a perfect impedance match. It can have several causes.

1. Characteristic Impedance Under the Slot.

The slot in the outer conductor increases the characteristic impedance in the area under the slot. The fractional change in impedance canbe calculated from the dimensions of the coaxial line, as follows:

$$\Delta Z_o = \frac{Z_o w^2}{4\pi^2 (x^2 - y^2)}$$

where

x = the radius of the inner conductor,
y = the radius of the outer conductor,
w = the width of the slot.

The minute change in impedance introduces a discontinuity which must be compensated for by a small increase in the diameter of the inner conductor under the slotted region. The slot should be accurately centered and free from burrs and dimensional defects.

2. Step Discontinuities.

Changes in diameter, such as occur in transitions from coaxial to a slab-type cross-section, cause severe reflections which cannot be compensated for completely enough for precision measurements over a frequency band. The Type 874-LBB avoids this difficulty by maintaining a true coaxial cross-section in both the slotted and unslotted sections of the line. The sole exception to this is a small step, to compensate for the slot effect, which causes only negligible VSWR. No dielectric support bead other than the one in the Type 874-BBL connector is necessary.

3. Connector Reflections.

A primary source of residual VSWR is reduced by use of the Type 874-BBL Connector.

Probe Effects.

1. Constancy of Probe Pickup.

Small irregularities in either the inner or the outer conductor of a slotted line lead to variations in probe penetration along the line. This variable is usually called "flatness" and is expressed in terms of equivalent VSWR. These variations cause corresponding changes in probe output even with a perfect termination and are easily confused with true VSWR, when the measured VSWR approaches the size of the flatness curve. For this reason the flatness specification determines the minimum VSWR measurable by conventional standing-wave indicators.

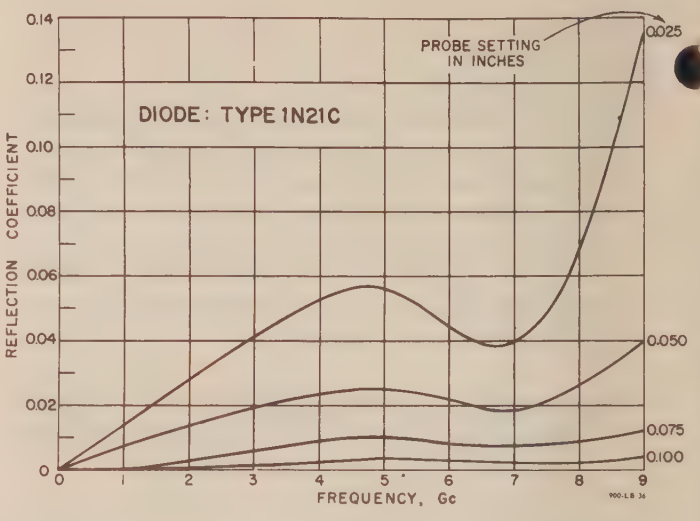


Figure 4-9. Probe reflections at four penetrations, with type 1N21C.

2. Probe Reflection.

Some of the incident wave in the slotted line is reflected by the probe and travels back toward the generator. If the generator is well matched, all is well, but a mismatched generator will re-reflect some of the energy and the probe will detect and respond to its own reflection, as well as to that of the termination. The magnitude of the erroneous VSWR thus detected is:

$$VSWR_e = \frac{1 + \Gamma_P \Gamma_G}{1 - \Gamma_P \Gamma_G}$$

where

Γ_P = the reflection coefficient of the probe
Γ_G = reflection coefficient of the generator.

The probe reflection depends upon frequency, probe penetration, probe tuning, and diode-detector characteristics. See Figure 4-9.

4.7 TYPE 874-LBB SLOTTED LINE

4.7.1 GENERAL

The Type 874-LBB Slotted Line comprises a slotted section mounted on a calibrated carriage struc-

ture which also mounts an adjustable probe and tuner. It has a nominal frequency range of 300 MHz to 8.5 GHz, but measurements can be made at low as 150 MHz (refer to paragraph 3.10).

Connections to the load and the generator are made through Type 874-BBL Connectors and the residual VSWR of the line and connectors is less than $1.01 + 0.0016\ f_{GHz}^2$ up to 7.5 GHz, 1.10 from 7.5 to to 8.5 GHz.

The line is based on a single slotted section 26 inches long. A 50-cm slot cut longitudinally in the top of the outer conductor permits insertion of the pickup probe. Thus, the *single* slotted section, accurately positioned at the time of factory installation, provides up to five octaves of coverage from UHF through X-band. The probe can travel a half-wavelength at the lowest normal test frequency (i.e., 50 centimeters at 300 MHz) with a residual slope that is very small (±1.25%).

The slotted section is an air-dielectric coaxial line, with inner and outer conductors made to close dimensional tolerances to ensure a characteristic impedance of 50.0 Ω.

4.7.2 PROBE CARRIAGE DRIVE

One electrostatic-pickup-probe assembly (rf probe) with external depth adjustment is furnished. The assembly mounts in the rigid cast carriage which transports the probe throughout the entire length of the slot. The mechanism for driving the carriage offers nearly constant probe coupling along the line, with negligible backlash.

In order to minimize the effects of any slight distortion in the line and the changes in effective probe coupling resulting from forces applied to the carriage, the driving knob is mounted in a fixed position of the right-hand-end casting and the carriage is driven by means of a nylon cord. The cord forms a complete loop, which is attached to the carriage at one point, and passes over an idler pulley on one end of the line and around a drum attached to the knob shaft on the other. The connection between the cord and the driving drum is obtained by means of friction, and one and a half turns of the cord around the drum have been found sufficient for positive drive without slippage. Since there are no teeth or grooves involved in the drive mechanism, a very smooth adjustment is obtained. Ball bearings are used on the drum and pulley shafts to reduce the driving force required and to minimize wear. A small ratchet-type take-up reel is mounted on the back of the carriage to permit adjustment of the tension in the nylon cord.

The fixed position of the driving knob, the use of ball bearings, and the durability of the nylon cord make the line easily adapted to motor drive, i.e., to the Type 1640-A Slotted Line Recorder System. A bevel gear is required to engage the motor drive.

4.7.3 PROBE CARRIAGE CONSTRUCTION (See Figure 4-10).

The probe carriage is made of cast brass and its honed sleeve bearing slides on the finely ground, chrome-plated surface of the outer conductor. Play in the carriage, which can cause rocking and consequent changes in probe coupling when the direction of travel is reversed, is negligible, since the tolerance of the bearing surface is 0.0001 inch. Probe travel is further stabilized by a second sleeve-type bearing machined in the carriage body. This consists of a semicircular bearing surface in the lower end of the casting which rides along the polished stainless-steel guide rod at the front of the instrument. This bearing surface prevents rotation of the carriage about its axis.

Rubber washers at each end of the slotted section, just inside the guide-rod supports, serve as bumpers to protect the mechanism in the event of carriage overdrive.

A felt washer, held in place by a metal ring nut, is mounted at each end of the carriage to prevent dirt and other foreign material, which may collect on the surface of the outer conductor, from entering the bearing. Oil holes in the top of the carriage permit these washers to be filled with oil for long-lasting lubrication of the bearing surfaces.

A 3/4-inch-diameter hole in the top of the carriage, beside the output connector, is tapped to receive either of two threaded probe assemblies. The small hole, in the center of the base of this opening, is the access for the pickup probe. A probe-shield assembly, consisting of a brass disk with a two-stepped hub on its underside, shields the probe from undesirable variation in its capacity to ground as it travels the slot. The hub is lined with clear polystyrene to insulate the probe from the rest of the carriage. The shield assembly is held in place by a retaining ring which seats in a groove at the base of the opening.

Beneath the probe mount, at the rear of the carriage, is a shallow, cylindrical cavity which houses the diode detector and a built-in by-pass capacitor. One of two symmetrically spaced holes in the inner wall of the cavity is the diode holder and the other provides access for a spring contact, which connects the

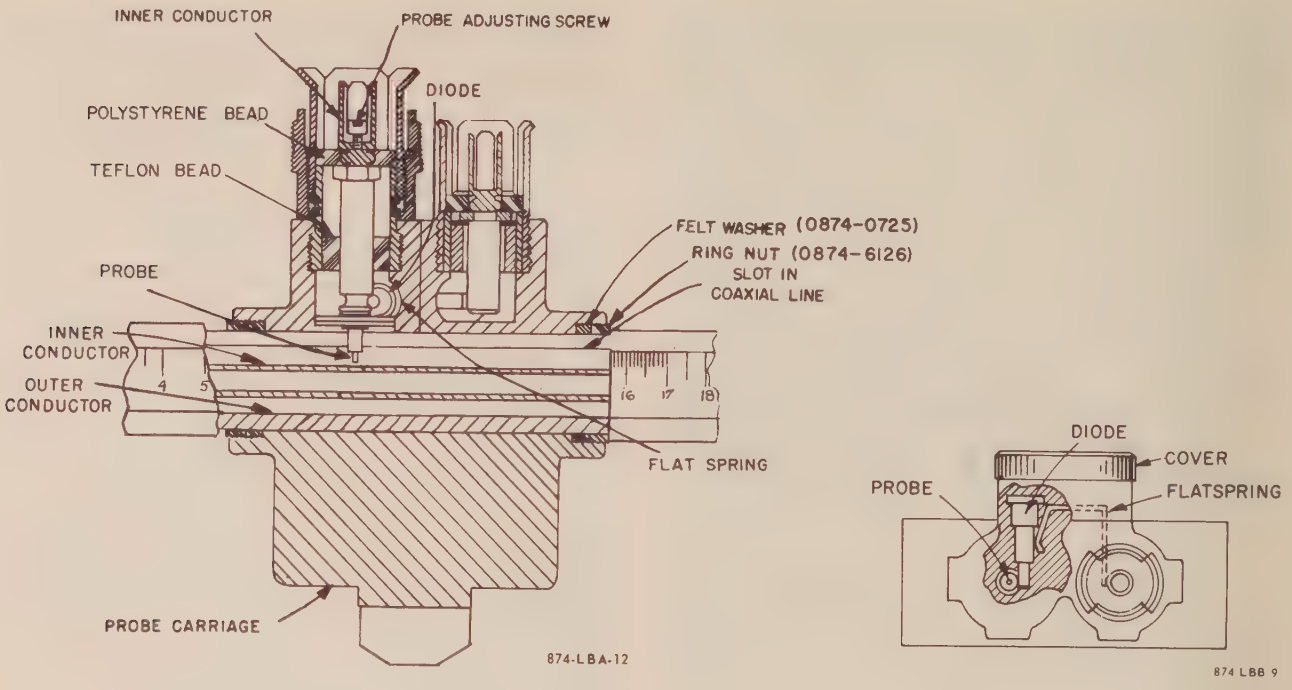


Figure 4-10. Cross-sectional views of the carriage on the Type 874-LBB Slotted Line, showing the diode mount and the adjustable probe.

diode output to the center conductor of the output connector.

The diode holder will also accept bolometers of a similar outline. The diode mounts small-end-first and bottoms in the holder; the small ends fits snugly in a concave ridge in the chuck holding the probe tip. The spring contact makes the connection at the large end of the diode and also clamps the diode securely in position.

The two interchangeable microwave diodes supplied, types 1N21C and 1N23B, furnish adequately overlapping coverage for the frequency range of the instrument. For low-noise applications, types 1N21F and 1N23F are suggested.

The flange at the wide end of the diode rests against a brass plate, which is insulated from the carriage body by a Mylar disk of the same shape as the plate, but with smaller-diameter holes. The plate and the opposing surface of the carriage body constitute a diode by-pass capacitor, with the Mylar disk as the dielectric. Plate, disk, and contact are fastened by a threaded stud that also secures the knurl-rimmed aluminum cover. The stud is insulated from plate and contact.

SECTION 5 SERVICE AND MAINTENANCE

5.1 WARRANTY

We warrant that each new instrument manufactured and sold by us is free from defects in material and workmanship, and that, properly used, it will perform in full accordance with applicable specifications for a period of two years after original shipment. Any instrument or component that is found within the two year period not to meet these standards after examination by our factory, Sales Engineering Office, or authorized repair agency personnel, will be repaired, or, at our option, replaced without charge, except for tubes or batteries that have given normal service.

5.2 SERVICE

The two-year warranty stated above attests the quality of materials and workmanship in our products. When difficulties do occur, our service engineers will assist in any way possible. If the difficulty cannot be eliminated by use of the following service instructions, please write or phone our Service Department (see rear cover), giving full information of the trouble and of steps taken to remedy it. Be sure to mention the serial and type numbers of the instrument.

Before returning an instrument to General Radio for service, please write to our Service Department or nearest Sales Engineering Office, requesting a Returned Material Tag. Use of this tag will ensure proper handling and identification. For instruments not covered by the warranty, a purchase order should be forwarded to avoid unnecessary delay.

5.3 DIODE CHECK (Figure 4-10).

To remove the detector diode, unscrew the cover on the back of the carriage and pull the diode from its socket.

The diode can be checked with a VOM (Simpson 260, or equivalent). Measure the resistance with both polarities of applied dc voltage. The resistance should be below 700 ohms in one direction and above 50,000 ohms in the other.

Occasionally, a diode that passes the above test may be noisy, as demonstrated by erratic output indication. Such a diode must be replaced.

5.4 CLEANING AND LUBRICATION

The Slotted Line should be kept in its storage box or covered when not in use to keep dirt from accumulating on the carriage track. The track should be cleaned and lubricated occasionally for best performance.

The felt washers shown in Figure 4-10 are libricated through the oil holes provided. Use a light oil and keep the oil ports filled so that there is a light oil

film on the outer tube. It may occasionally be necessary to tighten the retaining rings to keep the felt washers in contact with the tube. Do not tighten them too much, or they will make it difficult to slide the carriage, causing backlash.

When the track needs cleaning, spread a coat of kerosene or light oil, such as clock oil, over the whole outside of the outer conductor. Use a pipe cleaner or a cloth. Then slide the carriage back and forth several times to dislodge any dirt caught in the felt rings. Finally, wipe the track dry with a cloth. Repeat this procedure until the cloth does not pick up any dirt.

If the line is very dirty, remove and clean the felt washers. To remove them, unscrew the retaining washers at both ends of the carriage (see Figure 4-10 and pull out the felt. Clean the felt in a solvent. When replacing the felt washers, flatten them out and push them into place. Reload the felt washers with a light oil through the oil holes at the ends of the carriage.

An oil port at the bottom of the carriage permits lubrication at the point of contact with the tie bar. This is especially important if the slotted line is motor driven.

The slot in the outer conductor can be cleaned with a pipe cleaner.

CAUTION

Do not attempt to disassemble the line, this operation requires special tooling, and should be done be our service department.

5.5 CALIBRATION OF THE VARIATION IN PROBE COUPLING

The variation in probe coupling along the line can be calibrated and the measurements very easily corrected for the variations. A 1000-Hz signal of at least 10 volts from the audio oscillator is applied to the slotted line whose load end is open-circuited. The tuning stub and crystal are removed and the input to the amplifier (Type 1232 is suitable) is connected directly to the connector normally used for the tuning stub. The variation in indication on the amplifier meter is then recorded as a function of the probe position. The curve thus obtained can be applied to rf measurements. In this calibration, the diode is not used and the output is directly proportional to the coupling, and not to the square of the output as when the diode is employed.

The variations in probe coupling will change somewhat as the probe penetration is varied. Hence, for most accurate results, the calibration curve should be made with the same probe penetration as was used in the rf measurements, and preferably 0.100 inches out.

5.6 ADJUSTMENT OF NYLON CORD TENSION

The nylon cord will stretch slightly with time, causing some backlash. A take-up reel on the back of the carriage can be used to adjust the cord tension. The inner flange of the reel has a number of holes around its outer edge; a pin, on the carriage body, enters one of the holes to provide a ratchet-type lock. To turn the reel, first pull it out about 1/16 inch to withdraw the pin from the hole in the flange. Then rotate the reel to produce the desired cord tension, and lock it by pushing it in so that the pin enters one of the holes.

5.7 REPLACEMENT OF NYLON CORD

The nylon cord is very tough, and should last a long time unless it rubs against a sharp cutting edge. An additional cord can be obtained from General Radio Company. The cord is 0.045 inch in diameter and 74-1/2 inches long; part number is 0874-3690.

Install the cord as shown in Figures 5-1 and 5-2. Knot the cord near one end, and thread the other end through the hole in the anchor post. Then pass the cord around the idler pulley and wrap it 1-1/2 times around the drive drum. Make sure that the end of the first turn is on the knob side of the beginning of the first turn (see Figure 5-2) so that the turns travel in the correct direction on the drum. Then pass the cord around the anchor post and thread it through the hole in the outer flange of the take-up reel. Knot the cord near the end to keep it from slipping back through the hole. Then adjust the tension by pulling out the take-up reel, to disengage the pin. Rotate it clockwise until the action of the drive knob feels satisfactory. It may be necessary to slide the cord axially along the driving drum to center it properly and to prevent it from riding over the flange at one end.

5.8 CALIBRATION

5.8.1 GENERAL

The residual VSWR of the Type 874-LBB Slotted-Line may be calibrated accurately with GR900 components.[1] A Type 900-Q874, GR900-to-GR874 Adaptor is employed to convert to the GR900 system. The adaptor

[1] A. E. Sanderson, Nineteenth Annual Conference of the I.S.A., October 12, 1964. Available as a General Radio Reprint B 21.

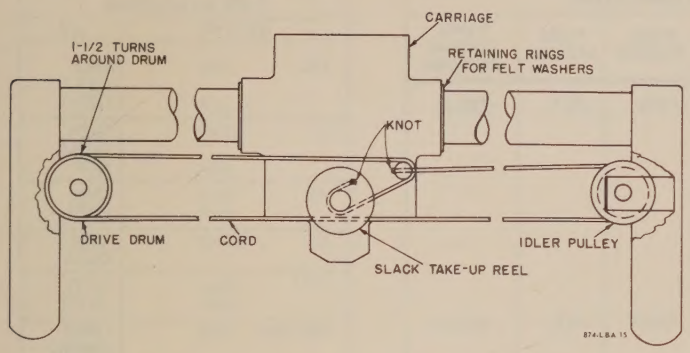


Figure 5-1. Rear view of the drive mechanism, showing the arrangement of the nylon cord.

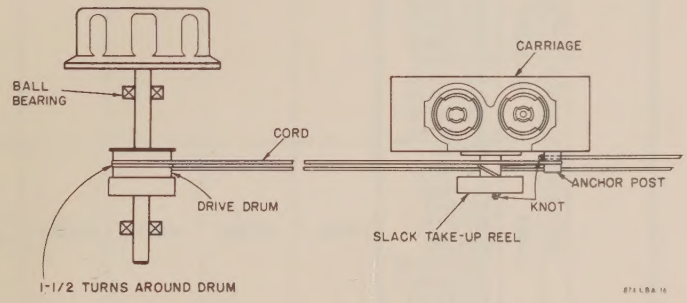


Figure 5-2. Installation of the nylon cord, viewed from the top of carriage.

VSWR is insignificant in this measurement because, by definition, the residual VSWR is specified for a mated pair of Type 874-BBL Connectors at the slotted-line terminals. The VSWR of the GR900 connector in the adaptor is considered negligible.

5.8.2 PROCEDURE

a. Connect the slotted-line in accordance with the standard procedure for measuring VSWR. Preferably the source should be matched, or a low-VSWR attenuator should be installed directly at the input connector of the slotted-line.

b. Install a Type 900-Q874 at the slotted-line measurement terminal to be calibrated.

c. Choose a Type 900-LZ Reference Air Line that is an odd multiple of a quarter wavelength at the calibration frequency or alternately choose the frequency to correspond to the quarter wavelength.

d. Install a Type 900-TUA or -TUB Tuner terminated in a Type 900-W50 Termination. Tune for the smallest possible VSWR.

e. Install the appropriate Type 900-LZ Air Line between the tuner and the Type 900-Q874 GR900 terminals and measure the VSWR. The slotted-line residual VSWR is,

$$(VSWR)_{SL} = 1 + \frac{[(VSWR) - 1]}{2}$$

f. If in step d unity VSWR is not achieved, the small VSWR that remains produces an error, but correction is possible. In fact if a tuner is not used, correction for the value obtained in step d is possible in the same manner. Measurement obtained in step d is supplemented by measuring the phase. Likewise, measurement obtained in step e is supplemented by measuring the phase. The two results are plotted on a Smith Chart. The Slotted-Line residual is the midpoint of the line joining the two measured values.

TYPE 874 COAXIAL COMPONENTS

TYPE 874 CABLE CONNECTORS

APPLICABLE CABLE TYPES		CONNECTOR TYPE	CABLE	CABLE LOCKING	PANEL FLANGED	PANEL LOCKING	PANEL LOCKING RECESSED
		874-A2	-CA	-CLA	-PBA	-PLA	-PRLA
	50-OHM	RG-8A/U RG-9B/U RG-10A/U RG-87A/U RG-116/U RG-156/U RG-165/U RG-166/U RG-213/U RG-214/U RG-215/U RG-225/U RG-227/U	-C8A	-CL8A	-PB8A	-PL8A	-PRL8A
	NON-50-OHM	RG-11A/U RG-12A/U RG-13A/U RG-63B/U RG-79B/U RG-89/U RG-144/U RG-146/U RG-149/U RG-216/U					
	50-OHM	874-A3 RG-29/U RG-55/U (Series) RG-58/U (Series) RG-141A/U RG-142A/U RG-159/U RG-223/U	-C58A	-CL58A	-PB58A	-PL58A	-PRL58A
	NON-50-OHM	RG-59/U RG-62/U (Series) RG-71B/U RG-140/U RG-210/U	-C62A	-CL62A	-PB62A	-PL62A	-PRL62A
	50-OHM	RG-174/U RG-188/U RG-316/U	-C174A	-CL174A	-PB174A	-PL174A	-PRL174A
	NON 50-OHM	RG-161/U RG-187/U RG-179/U					

Example: For a locking cable connector for RG-8A/U, order Type 874-CL8A.

TYPE 874 ADAPTORS

TO TYPE		874-
BNC	plug	QBJA QBJL*
	jack	QBPA
C	plug	QCJA QCJL*
	jack	QCP
HN	plug jack	QHJA QHPA
LC	plug	QLJA QLPA
LT	plug jack	QLTJ QLPT
Microdot	plug	QMDJ QMDJL*
	jack	QMDP
N	plug	QNJA QNJL*
	jack	QNP QNPL*
OSM/BRM	plug	QMMJ QMMJL*
	jack	QMMP QMMPL*
SC (Sandia)	plug	QSCJ QSCJL*
	jack	QSCP
TNC	plug	QTNJ QTNJL*
	jack	QTNP
UHF	plug	QUJ QUJL*
	jack	QUP
UHF 50-Ω Air Line	7/8-in. 1-5/8-in. 3-1/8-in.	QU1A QU2 QU3A

*Locking Type 874 Connector

Example: To connect Type 874 to a type N jack, order Type 874-QNP.

CONNECTOR ASSEMBLY TOOLS

TYPE 874–	FUNCTION
TOK	Tool Kit
TO58	Crimping Tool
TO8	Crimping Tool

OTHER COAXIAL ELEMENTS

TYPE 874-		TYPE 874-	
A2	50 Ω cable (low loss)	ML	component mount
A3	50 Ω cable	MB	coupling probe
D20L, D50L	20-, 50-cm adjustable stubs	MR, MRL	mixer-rectifier
EL, EL-L	90° ell	R20A, R20LA	patch cord, double shield
F185L	185-Mc/s low-pass filter	R22A, R22LA	patch cord, double shield
F500L	500-Mc/s low-pass filter	R33, R34	patch cord, single shield
F1000L	1000-Mc/s low-pass filter	T, TL	tee
F2000L	2000-Mc/s low-pass filter	TPD, TPDL	power divider
F4000L	4000-Mc/s low-pass filter	U	U-line section
FBL	bias insertion unit	UBL	balun
G3, G3L, G6, G6L	3-, 6-, 10-, and 20-dB attenuators	VCL	variable capacitor
G10, G10L		VI	voltmeter indicator
G20, G20L		VQ, VQL	voltmeter detector
GAL	adjustable attenuator	VR, VRL	voltmeter rectifier
JR	rotary joint	W100	100-Ω termination
K, KL	coupling capacitor	W200	200-Ω termination
L10, L10L	10-, 20-, and 30-cm rigid air lines	W50B, W50BL	50-Ω termination
L20, L20L		WN, WN3, WNL	short-circuit terminations
L30, L30L		WO, WO3, WOL	open-circuit terminations
LAL	33-58 cm adjustable line	X	insertion unit
LK10L, LK20L	constant-Z adjustable lines	XL	series inductor
LR	radiating line	Y	cliplock
LTL	trombone constant-Z line	Z	stand

MISCELLANEOUS COAXIAL CONNECTORS

CONNECTOR TYPE	TYPE NO.	USED WITH
Basic	874-B	50-ohm Air Line
Basic Locking	874-BBL	50-ohm Air Line
Panel Locking	874-PLT	Wire Load
Panel Locking Recessed	874-PRLT	Wire Lead
Panel Locking Feedthrough	874-PFL	Type 874 Patch Cords

L suffix indicates locking Type 874 Connector.

FOR COMPLETE DETAILS, REFER TO THE GENERAL RADIO CATALOG.

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Printed in USA